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LARP TQS01c Test Summary

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Content:

1. Introduction

TQS01 is a 1m long quadrupole model assembled at LBNL as part of the LARP program. TQS01c stands for the third test of this magnet. In these tests different coil sets have been used (coils 5,6,7, and 8 in the first test; coils 7, 8, 14, and 15 in TQS01b; coils 5,7,8, and 15 in TQS01c). This report documents the tests of TQS01c which were conducted at Fermilab in the Vertical Magnet Test Facility (VMTF) in order to study quench performance at superfluid helium temperature, and perform magnetic field measurements. According to a request by LBNL a slow cool down (maintaining $\Delta T<50$ K across the magnet) was executed, starting on the morning of February 28 to March 2, during which strain gauges and coil segment resistances were continuously monitored. Magnet performance tests started in the afternoon of March 5 and lasted until the morning of March 16.

2. Quench History

The magnet test program started with quench training at 20 A/s ramp rate at 4.5 K. At the beginning the quench detection threshold was set to 350 mV. A series of trips induced by voltage spikes (flux jumps) caused the increase of the detection threshold to 400 and 500 mV. The first magnet quench occurred at 8526 A with 500 mV threshold. After two more spike induced trips the threshold was set to 600 mV. During the following six current ramps two more trips occurred and the threshold was set to 700 mV. This threshold was used for all the rest of the test except for the MIITs studies.

At the eighth quench a plateau was reach at about 9560 A confirmed by the following 5 quenches. The magnet was then cooled down to 1.9 K and the training started from 9596 A followed by a step back to 9416 A. The rest of the training at 1.9 K showed a small but constant current increase up to 10490 A (quench 35) with a small step back at quench 32 (from 10340 A to 10100 A). Quenches 35 to 40 showed a plateau with current between 10475 and 10501 A. In the two subsequent quenches the ramp rate was 20 A/s up to 10 kA, and then 5 A/s after two minutes hold (quench current: 10526 A, and 10489 A). The magnet was then warmed up to 4.5 K holding the temperature at some intermediate steps in order to measure the quench current at 20 A/s.

Ramp rate studies were subsequently performed at 4.5 K, followed by quench protection studies and MIITs effect studies.

The quench history is presented in Figure 2.1 and in the following tables. These tables have been generated by processing the quench files. Comments in blue have been added subsequently based on notes taken during the test.

During magnet training all coils had at least two quenches. Coil 15 had most of the quenches during training and all quenches at the plateau and during temperature studies (Fig. 2.2)

Quench current temperature dependence and ramp rate dependence are shown in Figs. 3.1 and Fig 4.1 respectively. Protection heater and MIITs studies are presented in section 5 and 6.

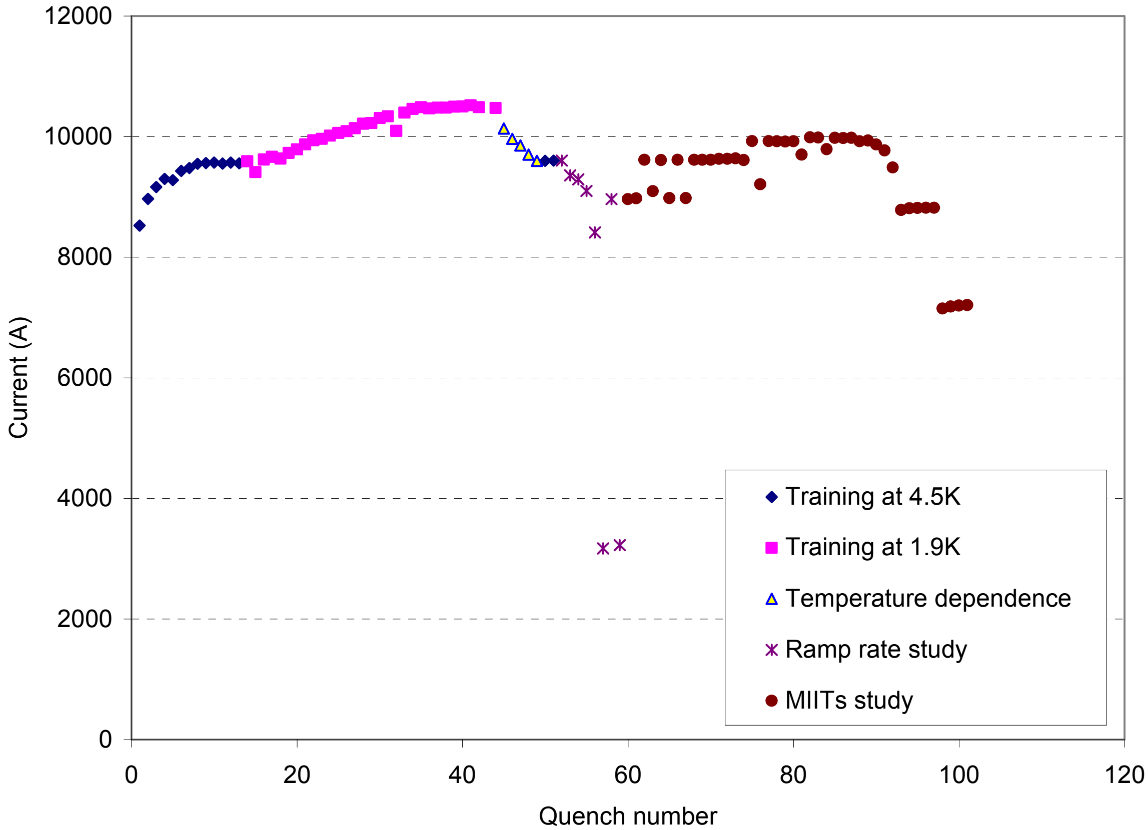


Figure 2.1. TQS01c quench history. Quench 43 is not shown because occurred during magnetic measurement. Quench protection heater studies were performed between quench 51 and 52.

TQS01c Quench History table with comments								
File	**Q No.**	**Current**	**dI/dt**	**t_{quench}**	**MIITs**	**Mag Temp Bot Left**	**Mag Temp Top Left**	**Comments**
tqs01.Quench.070227164332.150		**3**	0	1.0000	0.00	0.000	0.000	
tqs01.Quench.070302162331.717		**967**	72	-0.0057	0.12	4.455	4.452	DQD_COIL trip at about 900 A... investigating.
tqs01.Quench.070302173255.243		**1470**	100	-0.0001	0.16	4.455	4.450	all of the AQDs went off at the same time ?? at about 1350 A.
tqs01.Quench.070302180720.696		**1574**	19	-0.0070	0.21	4.453	4.451	perhaps another flux jump trip.
tqs01.Quench.070302182651.634		**3002**	0	-0.0748	1.32	4.457	4.456	Heater induced quench at 3000 A with 200 V
tqs01.Quench.070305130113.865		**1265**	-50	-0.0218	0.19	4.443	4.442	The PS trip at the ramp down at 1.5 kA at 50 A/s ramp down.
tqs01.Quench.070305145226.937	1	**8526**	20	-0.0091	4.06	4.438	4.435	Quench 01 at 8526 A, ramp = 20 A/s, T = 4.5 K - Threshold 500 mV
tqs01.Quench.070305152334.542		**967**	0	-0.6028	0.67	4.441	4.440	Quench 02 (trip?) I = 983A, ramp=20A/s, T=4.5K Spike
tqs01.Quench.070305153611.382		**1649**	19	-0.0070	0.24	4.441	4.440	Quench 03 I = 1650A, ramp = 20 A/s, T = 4.5K Spike ==> new threshold 600 mV
tqs01.Quench.070305160411.523	2	**8973**	20	-0.0085	4.16	4.441	4.439	quench 04 I = 8970 A, ramp = 20 A/s, T = 4.5K
tqs01.Quench.070305163721.108	3	**9160**	20	-0.0073	4.15	4.447	4.445	quench 05, I = 9163 A, ramp = 20 A/s, T = 4.45K
tqs01.Quench.070305170415.947	4	**9302**	20	-0.0118	4.61	4.445	4.443	quench 06 I = 9299 A, ramp = 20 A/s, T = 4.5K
tqs01.Quench.070305172159.668		**1477**	20	-0.0346	0.26	4.445	4.442	quench 07 I = 1480 A, ramp = 20 A/s, T = 4.5K Spike
tqs01.Quench.070305174414.221	5	**9286**	20	-0.0115	4.57	4.451	4.446	quench 08, I = 9280 A, ramp = 20 A/s, T = 4.5 K
tqs01.Quench.070305180959.938	6	**9431**	20	-0.0069	4.24	4.445	4.444	Quench 09, I = 9433 A, ramp = 20 A/s, T = 4.5K
tqs01.Quench.070305182226.273		**1010**	20	-0.0839	0.19	4.444	4.443	quench 10, I = 1015A, ramp = 20 A/s, T = 4.5K Spike ==> new threshold 700 mV
tqs01.Quench.070305190700.267	7	**9479**	20	-0.0095	4.51	4.447	4.445	Quench 11, I = 9479 A, ramp = 20 A/s, T = 4.5K
tqs01.Quench.070305193141.398	8	**9551**	20	-0.0111	4.66	4.447	4.446	quench 12, I = 9548 A, ramp = 20 A/s, T = 4.5k
tqs01.Quench.070305195537.447	9	**9562**	19	-0.0077	4.37	4.455	4.451	quench 13, I = 9562 A, ramp = 20 A/s, T = 4.5 K
tqs01.Quench.070305203017.539	10	**9571**	20	-0.0059	4.20	4.457	4.453	quench 14, I = 9569 A, ramp = 20 A/s, T = 4.5K□x
tqs01.Quench.070305205903.158	11	**9556**	19	-0.0066	4.25	4.466	4.461	quench 15, I = 9556 A, ramp = 20 A/s, T = 4.5 K
tqs01.Quench.070306094115.736	12	**9574**	20	-0.0069	4.35	4.451	4.453	20 A/s ramp to quench, at Iq=9570A
tqs01.Quench.070306103252.831	13	**9557**	20	-0.0220	4.3	4.452	4.451	Quench 17, I= 9577 A, Rate 20A/sec, T=4.5K
tqs01.Quench.070306155027.170	14	**9596**	20	-0.0034	4.09	1.870	1.870	Quench 18, I = 9592 A, ramp = 20 A/s, T = 1.9K
tqs01.Quench.070306161411.908	15	**9416**	20	-0.0123	4.80	1.875	1.874	quench 19, I = 9412 A, ramp = 20 A/s, T = 1.9K
tqs01.Quench.070306164441.720	16	**9622**	20	-0.0116	4.86	1.855	1.855	quench 20, I = 9618 A, ramp = 20 A/s, T = 1.87 K
tqs01.Quench.070306171458.775	17	**9665**	20	-0.0109	4.81	1.845	1.846	quench 21, I = 9665 A, ramp = 20 A/s, T = 1.85 K
tqs01.Quench.070306174825.503	18	**9640**	20	-0.0116	4.87	1.888	1.888	quench 22, I = 9636 A, ramp = 20 A/s, T = 1.85 K

tqs01.Quench.070306181517.269	19	**9735**	20	-0.0062	4.40	1.872	1.884	quench 23, I = 9731 A, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070306184224.483	20	**9791**	19	-0.0111	4.89	1.882	1.882	quench 24, I = 9787 A, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070306191115.374	21	**9871**	20	-0.0158	5.39	1.881	1.890	quench 25, I = 9850 A, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070306193953.193	22	**9942**	20	-0.0039	4.27	1.887	1.888	quench 26, I = 9938 A, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070306200723.408	23	**9964**	20	-0.0067	4.55	1.908	1.900	quench 27, I = 9962 A, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070306203509.877	24	**10021**	20	-0.0105	4.97	1.903	1.910	quench 28, I = ???, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070306205957.757	25	**10065**	20	-0.0105	4.97	1.906	1.900	quench 29, I = 10061 A, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070307122242.539	26	**10092**	20	-0.0032	4.33	1.889	1.876	Quench 30, I=10091A, ramp=20A/s, Te=1.88K
tqs01.Quench.070307125355.444	27	**10144**	20	-0.0064	4.59	1.867	1.868	quench 31, I = 10142 A, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070307132153.951	28	**10214**	20	-0.0041	4.38	1.866	1.855	quench 32, I ???, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070307134902.477	29	**10224**	20	-0.0036	4.35	1.861	1.862	quench 33, I = 10224 A, ramp = 20 A/s, T = 1.9K
tqs01.Quench.070307141553.052	30	**10314**	20	-0.0038	4.38	1.866	1.871	quench 34, I = 10310 A, ramp = 20 A/s, T = 1.9K
tqs01.Quench.070307144317.298	31	**10340**	20	-0.0031	4.33	1.850	1.852	quench 35, I = 10337 A, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070307150619.194	32	**10100**	20	-0.0032	4.26	1.877	1.878	quench 36, I = 10095, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070307153312.160	33	**10403**	20	-0.0088	5.00	1.847	1.847	quench 37, I = 10397 A, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070307160632.489		**10167**	20	-0.0001	3.50	1.857	1.861	Quench 38, I=10127A, rate=20A/sec, T=1.9K, trip on leads
tqs01.Quench.070307164633.855		**10427**	20	0.0000	3.53	1.883	1.884	Quench 30, trip on leads, I=10324A, rate =20A/s.
tqs01.Quench.070307171026.323	34	**10463**	21	-0.0036	4.43	1.891	1.892	quench 40, I = 10458 A, ramp = 20 A/s, T = 1.9 K
tqs01.Quench.070307174230.151	35	**10492**	20	-0.0028	4.35	1.875	1.879	Quench 41, AQD_Coil trip, I=10488A, rate=20A/s, Te=1.89K
tqs01.Quench.070307180946.997	36	**10475**	20	-0.0031	4.37	1.904	1.906	quench 42, I = 10469 A, ramp = 20 A/s T = 1.95 K
tqs01.Quench.070307184423.091	37	**10484**	20	-0.0029	4.37	1.899	1.900	Quench 43, I=10481A. Rate=20A/sec. Te=1.9K
tqs01.Quench.070307191706.650	38	**10479**	20	-0.0031	4.38	1.846	1.846	Quench 44 on coil, I=10478A, Rate=20A/s. Te=1.88K.
tqs01.Quench.070307195232.095	39	**10499**	19	-0.0029	4.38	1.868	1.869	Quench 45 on coil, I=10497A, Rate=20A/s. Te=1.88K.
tqs01.Quench.070307202125.595	40	**10501**	19	-0.0032	4.40	1.885	1.886	Quench 46 on coil, I=10499A., Rate=20A/s, Te=1.89K.
tqs01.Quench.070308100050.836	41	**10526**	4	-0.0088	5.08	1.902	1.903	Quench 47, I=10521A, Rate=20A/s (up to 10kA) and 5A/s (after 10kA). Te=1.9K
tqs01.Quench.070308103901.200	42	**10489**	4	-0.0081	4.93	1.868	1.869	Quench 48, I=10488A. Rate=20A/s(upto 10kA) and 5A/s(after 10kA). Te=1.89K.
	43	**10350**	50					Quench during magnetic measurement - Lost data
tqs01.Quench.070308201410.017		**0**	0	0.0000	0.00	0.000	0.000	
tqs01.Quench.070309105948.717		**0**	0	0.0000	0.00	0.000	0.000	
	44	**10477**	20			1.900	1.900	Lost data
tqs01.Quench.070309113209.493	45	**10135**	19	-0.0046	4.39	2.605	2.615	quench 50, I = 10134 A, ramp = 20 A/s, T = 2.6K
tqs01.Quench.070309121142.921	46	**9966**	20	-0.0053	4.38	3.219	3.236	quench 51, I = 9964 A, ramp = 20 A/s, T = 3.25 K
tqs01.Quench.070309123515.618	47	**9858**	19	-0.0055	4.33	3.583	3.594	quench 52, I = 9854 A, ramp 20 A/s, T = 3.58 K
tqs01.Quench.070309140937.832	48	**9701**	20	-0.0067	4.40	3.992	4.003	quench 53, Te=4.0K, I=~9800A (will put the exact numbers in comment), rate=20A/s.
tqs01.Quench.070309144928.641	49	**9602**	19	-0.0060	4.22	4.416	4.414	quench 54 at I=9601A. T=4.4K, Rate=20A/s.

tqs01.Quench.070309152808.566		**3001**	0	-0.0813	1.38	4.430	4.427	quench 55, protection heater studies, I=3000A, T=4.4K, Rate=20A/s. hfu_02 at 200V fired the quench.
tqs01.Quench.070309154324.746		**1118**	-20	-0.0435	0.18	4.430	4.430	Quench 56 when ramping down - Shlomo requested 2 more quenches at 4.5K to see the magnet performance - Spike
tqs01.Quench.070309162018.346	50	**9601**	20	-0.0063	4.26	4.441	4.438	quench 56, I=9598A at 4.44K, rate=20A/s.
tqs01.Quench.070309164511.289	51	**9603**	20	-0.0060	4.22	4.451	4.446	Quench 58 at I=9601A, rate=20A/s and Te=4.4K.
tqs01.Quench.070309171106.013		**3003**	0	-0.0456	1.05	4.442	4.438	Quench 59, heater studies going on. I=3000A, Te=4.4K, Fired HFU_02 at 300V.
tqs01.Quench.070309172722.734		**3001**	0	-0.0392	0.99	4.442	4.437	Quench 60, I=3000A, Te=4.4K, hfu_02 fired at 400V.
tqs01.Quench.070309175051.493		**5001**	0	-0.0211	2.07	4.445	4.440	Quench 61, I=5000A. Te=4.4K, fired hfu_02 at 400V.
tqs01.Quench.070309180721.594		**5004**	0	-0.0272	2.23	4.443	4.439	Quench 62, I=5000A, Rate=20A/s, Te=4.4K, fired hfu_02.
tqs01.Quench.070309182905.477		**5003**	0	-0.0423	2.62	4.437	4.435	Quench 63, I=5000A, Te=4.4K, fired hfu_02 at 200V
tqs01.Quench.070309185336.279		**8006**	0	-0.0202	4.30	4.443	4.439	Quench 64, I=8000A, Rate=20A/s, Te=4.4K, fired hfu_02 at 200V.
tqs01.Quench.070309191753.369		**8006**	0	-0.0130	3.80	4.446	4.438	Quench 65, I=8000A, Te=4.4K, fired hfu_02 at 300V.
tqs01.Quench.070309194032.957		**8004**	0	-0.0105	3.63	4.454	4.453	Quench 66, I=8000A, Te=4.4K, fired hfu_02 at 400V
tqs01.Quench.070309200939.358		**9411**	0	-0.0076	4.12	4.438	4.438	Quench 67, I=9400A, Rate=20A/s, Te=4.4K. Fired hfu_02 at 400V.
tqs01.Quench.070309203322.207		**9405**	0	-0.0091	4.28	4.446	4.442	Quench 68, I=9400A, 20A/s, Te=4.4K, fired hfu_02 at 300V.
tqs01.Quench.070309205458.892		**9406**	0	-0.0143	4.75	4.449	4.445	Quench 69, I=9400A., Te=4.4K, fired hfu_02 at 200V.
tqs01.Quench.070312164435.878	52	**9603**	20	-0.0060	4.26	4.427	4.426	Quench 70, we started ramp rate study at 4.4K. I=9607A at 20A/s.
tqs01.Quench.070312170656.263	53	**9359**	100	-0.0134	4.76	4.446	4.445	quench 71, I = 9359 A, ramp = 100 A/s, T = 4.44K
tqs01.Quench.070312172903.316	54	**9291**	122	-0.0118	4.57	4.445	4.446	quench 72, I = 9292 A, ramp 200 A/s, T = 4.45 K
tqs01.Quench.070312175026.599	55	**9101**	200	-0.0125	4.51	4.429	4.431	quench 73, I = 9099 A, ramp = 200 A/s, T = 4.4 K
tqs01.Quench.070312181453.187	56	**8411**	300	-0.0048	3.47	4.439	4.436	Quench 74 at I=8411A, Rate=300A, T=4.4K.
tqs01.Quench.070312184626.003	57	**3170**	352	-0.1616	2.39	4.435	4.430	Quench 75 at I=3227A, Rate=400A/s. T=4.4K
tqs01.Quench.070312190734.194	58	**8966**	250	-0.0147	4.60	4.437	4.433	Quench 76 at I=8967A, rate=250A/s. T=4.4K.
tqs01.Quench.070312192553.589	59	**3225**	350	-0.0143	0.89	4.433	4.431	quernch 77, I = 3231 A, ramp = 350 A/s, T = 4.4 K
tqs01.Quench.070312195617.882	60	**8966**	250	-0.0134	5.47	4.441	4.433	quench 78, I = 8968 A, ramp = 250 A/s, T = 4.43 K, dump delay = 25 ms
tqs01.Quench.070312202058.433	61	**8978**	250	-0.0129	6.05	4.437	4.434	quench 79, I = 8978 A, ramp = 250 A/s, T = 4.45K dump delay = 45 ms
tqs01.Quench.070313094326.023		**4**	0	-0.0035	0.00	4.437	4.434	
tqs01.Quench.070313121853.733	62	**9614**	20	-0.0063	4.27	0.000	0.000	ramp = 20 A/s, Dump 5 ms
tqs01.Quench.070313123808.269		**0**	0	-0.0020	0.00	0.000	0.000	
tqs01.Quench.070313130308.171	63	**9097**	198	-0.0123	6.39	0.000	0.000	ramp = 250 A/s, Dump 65 ms
tqs01.Quench.070313134409.170	64	**9611**	20	-0.0066	4.23	0.000	0.000	ramp = 20 A/s, Dump 5 ms

tqs01.Quench.070313140831.009	65	**8981**	250	-0.0127	6.51	4.453	4.444	ramp = 250 A/s, Dump 90 ms
tqs01.Quench.070313152204.724	66	**9615**	20	-0.0070	4.28	4.433	4.427	ramp = 20 A/s, Dump 5 ms
tqs01.Quench.070313154137.591	67	**8981**	250	-0.0160	6.87	4.437	4.432	ramp = 250 A/s, Dump 200 ms
tqs01.Quench.070313161252.035	68	**9617**	19	-0.0071	4.29	4.441	4.436	quench 86, I = 9617 A, ramp = 20 A/s, T = 4.45K
tqs01.Quench.070313164459.088	69	**9616**	20	-0.0066	5.97	4.445	4.439	quench 87, I = 9618 A, ramp = 20 A/s, T = 4.43K, Dump delay 50 ms
tqs01.Quench.070313171540.528	70	**9616**	20	-0.0064	6.27	4.443	4.437	quench 88, I = 9614 A, ramp = 20 A/s, T = 4.44 K, Dump dealy 100 ms
tqs01.Quench.070313174803.661	71	**9632**	20	-0.0069	6.34	4.443	4.438	quench 89, I = 9629 A, ramp = 20 A/s, T = 4.44K, Dump delay 250 ms
tqs01.Quench.070313182743.141	72	**9630**	19	-0.0064	6.83	4.440	4.439	Quench 90, I=9628A, Dump delay 257ms, Heater delay 7.6ms, rate=20A/s, T=4.4K.
tqs01.Quench.070313190544.467	73	**9641**	20	-0.0073	7.50	4.437	4.431	quench 91, I = 9640 A, ramp = 20 A/s, T = 4.4K, Dump delay 265 ms, PHeater delay 15.6 ms□Rate
tqs01.Quench.070313194543.628	74	**9612**	20	-0.0084	7.95	4.435	4.431	quench 92, I = 9611, ramp = 20 A/s, T = 4.4K, Dump delay 270 ms, PHeater delay 21.2 ms
tqs01.Quench.070313202919.217	75	**9926**	20	-0.0071	8.16	4.434	4.432	quench 93, I = 9924 A, ramp = 20 A/s, T = 4.43K, Dump 276 ms PHeater 27.3 ms
tqs01.Quench.070313205845.334	76	**9211**	19	-0.0101	4.39	4.438	4.430	quench 94, I = 9212 A, ramp = 20 A/s, T = 4.44 K, Dump 5 ms, PHeater 0 ms
tqs01.Quench.070313212139.437	77	**9927**	20	-0.0063	4.33	4.434	4.435	quench 95, I = 9928 A, ramp = 20 A/s, T = 4.4 K, Dump 5 ms, PHeater 0 ms
tqs01.Quench.070313214428.697	78	**9924**	20	-0.0057	4.28	4.439	4.432	quench 96, I = 9922 A, ramp = 20 A/s, T = 4.4 K, dump 5 ms, PHeater 0 ms
tqs01.Quench.070314143026.727		**1**	0	-0.1945	0.04	4.428	4.428	don't know why - no welding. save data to look at the cause.
tqs01.Quench.070314144411.388	79	**9918**	19	-0.0060	4.36	4.436	4.431	quench 97, I = 9912 A, ramp = 20 A/s, T = 4.45 K, dump 5 ms
tqs01.Quench.070314172755.661	80	**9923**	20	-0.0062	8.07	4.431	4.429	quench 98, I = 9922 A, ramp = 20 A/s, T = 4.45 K Dump 280 ms, PHeater 30.7 ms
tqs01.Quench.070314181635.332	81	**9703**	20	-0.0041	4.06	4.449	4.444	quench 99, I = 9699 A, ramp = 20 A/s, T = 4.45 K, standard dump and heater delay
tqs01.Quench.070314184853.444	82	**9989**	20	-0.2071	4.40	4.441	4.432	quench 100, I = 9990 A, ramp = 20 A/s, T = 4.45 K, standard delays
tqs01.Quench.070314194009.492	83	**9983**	20	-0.0035	7.82	4.450	4.440	quench 101, I = 9980 A, ramp = 20 A/s, T = 4.44 K, dump 289 ms, Protect heater 40 ms
tqs01.Quench.070314202926.124	84	**9792**	20	-0.0064	4.31	4.459	4.447	quench 102, I = 9790 A, ramp = 20 A/s, T = 4.45 K, no delays
tqs01.Quench.070314205544.003	85	**9982**	20	-0.0046	4.18	4.448	4.442	quench 103, I = 9977 A, ramp = 20 A/s, T = 4.44 K, NO delays

tqs01.Quench.070315115603.030	86	**9977**	19	-0.0042	4.22	4.451	4.447	quench 104, I = 9974 A, ramp = 20 A/s, T = 4.45 K, detect thres 1.25 V, standard delays
tqs01.Quench.070315123423.553	87	**9979**	20	-0.0064	7.51	4.455	4.453	Quench 105, I=9975.3A, detect thresh=1.25V, Dump delay 300ms, Heater delay 80ms, rate=20A/s, T=4.44K
tqs01.Quench.070315130807.526	88	**9925**	20	-0.0091	4.59	4.458	4.451	quench 106, I = 9922 A, ramp = 20 A/s, T = 4.44K , standard delays
tqs01.Quench.070315135406.786	89	**9935**	20	-0.0059	7.54	4.448	4.446	quench 107, I = 9930 A, ramp = 20 A/s, T = 4.4K, Dump 300 ms, Heaters 100 ms
tqs01.Quench.070315143047.299	90	**9872**	20	-0.0097	7.75	4.456	4.453	quench 108, ramp = 20 A/s, T = 4.44K Dump 300 ms, NO heaters, detection 3V
tqs01.Quench.070315153507.444	91	**9770**	20	-0.0134	8.08	4.453	4.449	quench 109, I = 9765 A, ramp = 20 A/s, T = 4.45 K Dump 300 ms, NO heaters, detect 4V
tqs01.Quench.070315183145.732	92	**9487**	20	-0.0136	8.70	4.455	4.452	quench 110, I = 9480 A, ramp = 20 A/s, T = 4.45K, Detection 7V, Dump 300 ms, NO heaters
tqs01.Quench.070315191243.471	93	**8785**	20	-0.0245	5.22	4.461	4.460	quench 111, I = 8781 A, ramp = 20 A/s, T = 4.45K, standard delays
tqs01.Quench.070315193942.342	94	**8814**	20	-0.0238	5.18	4.450	4.443	quench 112, I = 8811 A, ramp = 20 A/s, T = 4.44K, standard delays
tqs01.Quench.070315200356.056	95	**8819**	20	-0.0262	5.35	4.457	4.451	quench 113, I = 8811 A, ramp = 20 A/s, T = 4.45K, Standard delays
tqs01.Quench.070315203136.000	96	**8822**	20	-0.0241	5.20	4.459	4.449	quench 114, I = 8818 A, ramp = 20 A/s, T = 4.45K, standard delays
tqs01.Quench.070315205716.269	97	**8822**	20	-0.0238	9.53	4.458	4.457	quench 115, I = 8817 A, ramp = 20 A/s, T = 4.45K, dump 300 ms, NO heaters, Detect 7V
tqs01.Quench.070315213106.928	98	**7148**	20	-0.0489	5.09	4.459	4.456	quench 116, I = 7145, ramp = 20 A/s, T = 4.45K, standard delays
tqs01.Quench.070316100850.826	99	**7184**	20	-0.0442	4.96	4.453	4.450	quench 117, I = 7180 A, ramp = 20 A/s, T = 4.45 K, standard delays
tqs01.Quench.070316103450.084	100	**7200**	20	-0.0483	5.11	4.455	4.447	quench 118, I=7196 A. Rate=20A/s, T=4.4K, standard delays.
tqs01.Quench.070316110436.334	101	**7207**	20	-0.0451	4.97	4.458	4.451	Quench 119, I=7203A. Rate=20A/s, T=4.4K, standard delays.

TQS01c Quench History table with first quenching segments

File	Q No.	Current	dI/dt	t_{quench}	QDC	1st VTseg	t_{rise}	2nd VTseg	t_{rise}	3rd VTseg	t_{rise}	VSDS run
tqs01.Quench.070227164332.150		**3**	0	1.0000	GndRef	------------	----	------------	----	------------	----	
tqs01.Quench.070302162331.717		**967**	72	-0.0057	WcoilGnd	08A3_08A2	-0.0034	08A7_08A6	-0.0034	08B2_08B3	-0.0029	
tqs01.Quench.070302173255.243		**1470**	100	-0.0001	WcoilGnd	08A8_08A7	-0.0094	08B5_08A8	-0.0087	08B1_08B2	-0.0066	
tqs01.Quench.070302180720.696		**1574**	19	-0.0070	HcoilHcoil	05B5_05B4	-0.0049	05A2_05A3	-0.0046	05B3_05B2	-0.0046	
tqs01.Quench.070302182651.634		**3002**	0	-0.0748	HcoilHcoil	05B2_05B1	-0.0109	05B3_05B2	-0.0091	08B2_08B3	-0.0074	
tqs01.Quench.070305130113.865		**1265**	-50	-0.0218	HcoilHcoil	07B2_07B3	-0.0214	08A3_08A2	-0.0214	08B1_08B2M_2	-0.0213	
tqs01.Quench.070305145226.937	1	**8526**	20	-0.0091	HcoilHcoil	15A6_15A8	-0.0098	15A5_15A6	-0.0085	05A1_05A2M_2	-0.0056	1
tqs01.Quench.070305152334.542		**967**	0	-0.6028	HcoilHcoil	15A6_15A8	-0.0067	05A2_05A3	-0.0060	05B3_05B2	-0.006	2
tqs01.Quench.070305153611.382		**1649**	19	-0.0070	HcoilHcoil	15A5_15A6	-0.0063	15A4_15A5	-0.0060	15A6_15A8	-0.0053	3
tqs01.Quench.070305160411.523	2	**8973**	20	-0.0085	HcoilHcoil	15A6_15A8	-0.0094	05B5_05B4	-0.0056	05A1_05A2M_2	-0.0056	4
tqs01.Quench.070305163721.108	3	**9160**	20	-0.0073	HcoilHcoil	15A6_15A8	-0.0077	15A5_15A6	-0.0067	15A8_15B6	-0.0015	5
tqs01.Quench.070305170415.947	4	**9302**	20	-0.0118	HcoilHcoil	07A7_07A6	-0.0050	07B3_07B4	-0.0031	V1_TrigCvtB2	-0.0003	6
tqs01.Quench.070305172159.668		**1477**	20	-0.0346	HcoilHcoil	08B4_08B5	-0.0193	15A6_15A8	-0.0052	15A4_15A5	-0.005	7
tqs01.Quench.070305174414.221	5	**9286**	20	-0.0115	HcoilHcoil	07A8_07A7	-0.0119	05A2_05A3	-0.0053	08A3_08A2	-0.0053	8
tqs01.Quench.070305180959.938	6	**9431**	20	-0.0069	HcoilHcoil	15A6_15A8	-0.0077	05A1_05A2M_2	-0.0042	05A2_05A3	-0.0041	9
tqs01.Quench.070305182226.273		**1010**	20	-0.0839	HcoilHcoil	08A7_08A6	-0.0035	08B2_08B3	-0.0035	08A3_08A2	-0.0034	10
tqs01.Quench.070305190700.267	7	**9479**	20	-0.0095	HcoilHcoil	15A8_15B6	-0.0105	15A6_15A8	-0.0062	05B5_05B4	-0.0053	11
tqs01.Quench.070305193141.398	8	**9551**	20	-0.0111	HcoilHcoil	08B5_08A8	-0.0118	08A8_08A7	-0.0105	08A6_08A5	-0.005	12
tqs01.Quench.070305195537.447	9	**9562**	19	-0.0077	HcoilHcoil	15A6_15A8	-0.0078	15A5_15A6	-0.0062	05A5_05A6	-0.0031	13
tqs01.Quench.070305203017.539	10	**9571**	20	-0.0059	HcoilHcoil	15A6_15A8	-0.0071	15A5_15A6	-0.0034	05A5_05A6	-0.002	14
tqs01.Quench.070305205903.158	11	**9556**	19	-0.0066	HcoilHcoil	15A6_15A8	-0.0071	15A5_15A6	-0.0032	V1_TrigCvtB2	-0.0003	15
tqs01.Quench.070306094115.736	12	**9574**	20	-0.0069	HcoilHcoil	15A6_15A8	-0.0070	15A5_15A6	-0.0041	05A2_05A3	-0.0022	16
tqs01.Quench.070306103252.831	13	**9557**	20	-0.0220	HcoilHcoil	15A6_15A8	-0.0074	05A2_05A3	-0.0041	05B3_05B2	-0.0039	17
tqs01.Quench.070306155027.170	14	**9596**	20	-0.0034	HcoilHcoil	15A8_15B6	-0.0042	15A6_15A8	-0.0041	15B6_15B5	-0.0024	18
tqs01.Quench.070306161411.908	15	**9416**	20	-0.0123	HcoilHcoil	07A8_07A7	-0.0136	08B2_08B3	-0.0088	05A5_05A6	-0.0087	19
tqs01.Quench.070306164441.720	16	**9622**	20	-0.0116	HcoilHcoil	05A6_05A7	-0.0130	05A1_05A2M_2	-0.0108	15A2_15A3	-0.0073	20
tqs01.Quench.070306171458.775	17	**9665**	20	-0.0109	HcoilHcoil	08A7_08A6	-0.0123	08A5_08A4	-0.0080	07B2_07B3	-0.0073	21
tqs01.Quench.070306174825.503	18	**9640**	20	-0.0116	HcoilHcoil	08B5_08A8	-0.0132	08A4_08A3	-0.0105	08A5_08A4	-0.009	22

tqs01.Quench.070306181517.269	19	**9735**	20	-0.0062	HcoilHcoil	15A8_15B6	-0.0076	15A5_15A6	-0.0045	05A2_05A3	-0.0038	23
tqs01.Quench.070306184224.483	20	**9791**	19	-0.0111	HcoilHcoil	07A8_07A7	-0.0119	08A3_08A2	-0.0091	08B2_08B3	-0.0091	24
tqs01.Quench.070306191115.374	21	**9871**	20	-0.0158	HcoilHcoil	15A6_15A8	-0.0066	15A5_15A6	-0.0041	05A5_05A6	-0.0022	25
tqs01.Quench.070306193953.193	22	**9942**	20	-0.0039	HcoilHcoil	15A6_15A8	-0.0045	15A5_15A6	-0.0034	15A8_15B6	-0.0028	26
tqs01.Quench.070306200723.408	23	**9964**	20	-0.0067	WcoilIdot	15A6_15A8	-0.0053	15A5_15A6	-0.0041	15B6_15B5	-0.0028	27
tqs01.Quench.070306203509.877	24	**10021**	20	-0.0105	HcoilHcoil	07A7_07A6	-0.0049	07B3_07B4	-0.0045	08A3_08A2	-0.0015	28
tqs01.Quench.070306205957.757	25	**10065**	20	-0.0105	HcoilHcoil	07A8_07A7	-0.0108	08B2_08B3	-0.0045	05A5_05A6	-0.0042	29
tqs01.Quench.070307122242.539	26	**10092**	20	-0.0032	HcoilHcoil	15A6_15A8	-0.0045	15A5_15A6	-0.0041	15A8_15B6	-0.0025	VSDS failure
tqs01.Quench.070307125355.444	27	**10144**	20	-0.0064	HcoilHcoil	08B5_08A8	-0.0070	08A7_08A6	-0.0069	08A8_08A7	-0.0067	
tqs01.Quench.070307132153.951	28	**10214**	20	-0.0041	HcoilHcoil	15A8_15B6	-0.0034	15A6_15A8	-0.0028	15A5_15A6	-0.0021	
tqs01.Quench.070307134902.477	29	**10224**	20	-0.0036	HcoilHcoil	15A6_15A8	-0.0038	15A5_15A6	-0.0029	15A8_15B6	-0.0027	
tqs01.Quench.070307141553.052	30	**10314**	20	-0.0038	HcoilHcoil	15A6_15A8	-0.0046	15A5_15A6	-0.0036	05A5_05A6	-0.0017	
tqs01.Quench.070307144317.298	31	**10340**	20	-0.0031	HcoilHcoil	15A6_15A8	-0.0038	15A5_15A6	-0.0029	15A8_15B6	-0.0022	
tqs01.Quench.070307150619.194	32	**10100**	20	-0.0032	HcoilHcoil	15A6_15A8	-0.0042	15A5_15A6	-0.0032	15A8_15B6	-0.0025	
tqs01.Quench.070307153312.160	33	**10403**	20	-0.0088	HcoilHcoil	05A7_05B6	-0.0102	05A6_05A7	-0.0078	15B5_15B4	-0.0032	
tqs01.Quench.070307160632.489		**10167**	20	-0.0001	WcoilGnd	V1_TrigCvtB 2	-0.0003	15A6_15A8	-0.0001	15B4_15B3	-0.0001	
tqs01.Quench.070307164633.855		**10427**	20	0.0000	WcoilGnd	15A6_15A8	-0.0001	15B4_15B3	-0.0001	V1_TrigCvtB 2	-0.0001	
tqs01.Quench.070307171026.323	34	**10463**	21	-0.0036	HcoilHcoil	15A6_15A8	-0.0048	15A5_15A6	-0.0035	15B6_15B5	-0.0024	
tqs01.Quench.070307174230.151	35	**10492**	20	-0.0028	HcoilHcoil	15A6_15A8	-0.0036	15A5_15A6	-0.0028	15A8_15B6	-0.002	
tqs01.Quench.070307180946.997	36	**10475**	20	-0.0031	HcoilHcoil	15A6_15A8	-0.0045	15A5_15A6	-0.0028	15B6_15B5	-0.0014	
tqs01.Quench.070307184423.091	37	**10484**	20	-0.0029	HcoilHcoil	15A6_15A8	-0.0043	15A5_15A6	-0.0028	15B6_15B5	-0.0021	
tqs01.Quench.070307191706.650	38	**10479**	20	-0.0031	HcoilHcoil	15A6_15A8	-0.0045	15A5_15A6	-0.0031	15A4_15A5	-0.0024	
tqs01.Quench.070307195232.095	39	**10499**	19	-0.0029	HcoilHcoil	15A6_15A8	-0.0042	05A2_05A3	-0.0031	05A4_05A5	-0.0031	
tqs01.Quench.070307202125.595	40	**10501**	19	-0.0032	HcoilHcoil	15A6_15A8	-0.0043	15A5_15A6	-0.0027	05B3_05B2	-0.0022	
tqs01.Quench.070308100050.836	41	**10526**	4	-0.0088	HcoilHcoil	15B4_15B3	-0.0097	15B5_15B4	-0.0038	08A6_08A5	-0.0018	
tqs01.Quench.070308103901.200	42	**10489**	4	-0.0081	HcoilHcoil	15B4_15B3	-0.0097	15B5_15B4	-0.0039	05A5_05A6	-0.0032	
	43	**10350**	50									
tqs01.Quench.070308201410.017		**0**	0	0.0000		------------	----	------------	----	------------	----	
tqs01.Quench.070309105948.717		**0**	0	0.0000		------------	----	------------	----	------------	----	
	44	**10477**	20									
tqs01.Quench.070309113209.493	45	**10135**	19	-0.0046	HcoilHcoil	15A6_15A8	-0.0050	15A5_15A6	-0.0029	15B6_15B5	-0.0021	
tqs01.Quench.070309121142.921	46	**9966**	20	-0.0053	HcoilHcoil	15A6_15A8	-0.0062	15A5_15A6	-0.0031	15B6_15B5	-0.0017	
tqs01.Quench.070309123515.618	47	**9858**	19	-0.0055	HcoilHcoil	15A6_15A8	-0.0063	15A5_15A6	-0.0032	05A2_05A3	-0.0024	
tqs01.Quench.070309140937.832	48	**9701**	20	-0.0067	HcoilHcoil	15A6_15A8	-0.0071	15A5_15A6	-0.0050	05A1_05A2 M_2	-0.0022	

tqs01.Quench.070309144928.641	49	**9602**	19	-0.0060	HcoilHcoil	15A6_15A8	-0.0070	05A4_05A5	-0.0036	05A5_05A6	-0.0036	
tqs01.Quench.070309152808.566		**3001**	0	-0.0813	HcoilHcoil	05B5_05B4	-0.0808	05A2_05A3	-0.0802	05B3_05B2	-0.0795	
tqs01.Quench.070309154324.746		**1118**	-20	-0.0435	HcoilHcoil	15A6_15A8	-0.0045	15B3_15B2	-0.0029	15A2_15A3	-0.0028	
tqs01.Quench.070309162018.346	50	**9601**	20	-0.0063	HcoilHcoil	15A6_15A8	-0.0071	15A5_15A6	-0.0041	05A2_05A3	-0.0029	
tqs01.Quench.070309164511.289	51	**9603**	20	-0.0060	HcoilHcoil	15A6_15A8	-0.0069	05B3_05B2	-0.0057	05A5_05A6	-0.0056	
tqs01.Quench.070309171106.013		**3003**	0	-0.0456	HcoilHcoil	05B5_05B4	-0.0459	08B4_08B5	-0.0456	05A2_05A3	-0.0434	
tqs01.Quench.070309172722.734		**3001**	0	-0.0392	HcoilHcoil	08B4_08B5	-0.0400	08A6_08A5	-0.0398	05B3_05B2	-0.0384	
tqs01.Quench.070309175051.493		**5001**	0	-0.0211	HcoilHcoil	08B4_08B5	-0.0242	05B5_05B4	-0.0203	08A3_08A2	-0.0189	
tqs01.Quench.070309180721.594		**5004**	0	-0.0272	HcoilHcoil	08B4_08B5	-0.0290	05B5_05B4	-0.0262	05B3_05B2	-0.0231	
tqs01.Quench.070309182905.477		**5003**	0	-0.0423	HcoilHcoil	08B4_08B5	-0.0451	05B5_05B4	-0.0413	05B3_05B2	-0.0209	
tqs01.Quench.070309185336.279		**8006**	0	-0.0202	HcoilHcoil	08B4_08B5	-0.0227	05B5_05B4	-0.0192	08A3_08A2	-0.0169	
tqs01.Quench.070309191753.369		**8006**	0	-0.0130	HcoilHcoil	08B4_08B5	-0.0154	08B3_08B4	-0.0122	05B5_05B4	-0.0118	
tqs01.Quench.070309194032.957		**8004**	0	-0.0105	HcoilHcoil	08B4_08B5	-0.0126	08B3_08B4	-0.0112	05B5_05B4	-0.0092	
tqs01.Quench.070309200939.358		**9411**	0	-0.0076	HcoilHcoil	08B4_08B5	-0.0098	08A6_08A5	-0.0091	08A7_08A6	-0.0085	
tqs01.Quench.070309203322.207		**9405**	0	-0.0091	HcoilHcoil	08B4_08B5	-0.0126	08B3_08B4	-0.0088	05B5_05B4	-0.0083	
tqs01.Quench.070309205458.892		**9406**	0	-0.0143	HcoilHcoil	08B4_08B5	-0.0168	05B5_05B4	-0.0130	08B3_08B4	-0.0126	
tqs01.Quench.070312164435.878	52	**9603**	20	-0.0060	HcoilHcoil	15A6_15A8	-0.0069	15A5_15A6	-0.0028	05B5_05B4	-0.0015	
tqs01.Quench.070312170656.263	53	**9359**	100	-0.0134	HcoilHcoil	15A6_15A8	-0.0106	15A5_15A6	-0.0042	V1_TrigCvtB2	-0.0001	
tqs01.Quench.070312172903.316	54	**9291**	122	-0.0118	HcoilHcoil	15A6_15A8	-0.0113	15A5_15A6	-0.0049	V1_TrigCvtB2	-0.0003	
tqs01.Quench.070312175026.599	55	**9101**	200	-0.0125	HcoilHcoil	15A6_15A8	-0.0129	15A5_15A6	-0.0056	V1_TrigCvtB2	-0.0003	
tqs01.Quench.070312181453.187	56	**8411**	300	-0.0048	HcoilHcoil	05A7_05B6	-0.0048	05A2_05A3	-0.0036	15A2_15A3	-0.0032	
tqs01.Quench.070312184626.003	57	**3170**	352	-0.1616	HcoilHcoil	05A3_05A4	-0.0148	05A2_05A3	-0.0146	05B3_05B2	-0.0109	
tqs01.Quench.070312190734.194	58	**8966**	250	-0.0147	HcoilHcoil	15A6_15A8	-0.0137	05A1_05A2M_2	-0.0076	15A5_15A6	-0.0063	
tqs01.Quench.070312192553.589	59	**3225**	350	-0.0143	HcoilHcoil	05A3_05A4	-0.0101	V1_TrigCvtB2	-0.0003	HP_HN	0.0027	
tqs01.Quench.070312195617.882	60	**8966**	250	-0.0134	HcoilHcoil	15A6_15A8	-0.0136	05B5_05B4	-0.0085	05A7_05B6	-0.0084	
tqs01.Quench.070312202058.433	61	**8978**	250	-0.0129	HcoilHcoil	15A6_15A8	-0.0134	15A5_15A6	-0.0064	05A7_05B6	-0.0057	
tqs01.Quench.070313094326.023		**4**	0	-0.0035	SlWcoil	V1_TrigCvtB2	-0.0003	05A1_05A2M_2	-0.0001	HP_HN	0	
tqs01.Quench.070313121853.733	62	**9614**	20	-0.0063	HcoilHcoil	15A6_15A8	-0.0073	15A5_15A6	-0.0031	V1_TrigCvtB2	-0.0001	
tqs01.Quench.070313123808.269		**0**	0	-0.0020	WcoilGnd	05B5_05B4	-0.0001	15B5_15B4	-0.0001	V1_TrigCvtB2	-0.0001	
tqs01.Quench.070313130308.171	63	**9097**	198	-0.0123	HcoilHcoil	15A6_15A8	-0.0126	15A5_15A6	-0.0059	15A8_15B6	-0.0032	
tqs01.Quench.070313134409.170	64	**9611**	20	-0.0066	HcoilHcoil	15A6_15A8	-0.0074	15A5_15A6	-0.0029	Q24P_Q24N	-0.002	
tqs01.Quench.070313140831.009	65	**8981**	250	-0.0127	HcoilHcoil	15A6_15A8	-0.0137	15A8_15B6	-0.0085	05A1_05A2	-0.0076	

tqs01.Quench.070313152204.724	66	**9615**	20	-0.0070	HcoilHcoil	15A6_15A8	-0.0076	15A5_15A6	-0.0036	05A2_05A3	-0.0032	
tqs01.Quench.070313154137.591	67	**8981**	250	-0.0160	WcoilGnd	15A6_15A8	-0.0133	08A3_08A2	-0.0064	08A8_08A7	-0.0064	
tqs01.Quench.070313161252.035	68	**9617**	19	-0.0071	HcoilHcoil	15A6_15A8	-0.0073	15A5_15A6	-0.0038	V1_TrigCvt B2	-0.0003	
tqs01.Quench.070313164459.088	69	**9616**	20	-0.0066	HcoilHcoil	15A6_15A8	-0.0076	15A8_15B6	-0.0052	15B6_15B5	-0.0041	
tqs01.Quench.070313171540.528	70	**9616**	20	-0.0064	HcoilHcoil	15A6_15A8	-0.0073	15A5_15A6	-0.0029	15B6_15B5	-0.0017	
tqs01.Quench.070313174803.661	71	**9632**	20	-0.0069	HcoilHcoil	15A6_15A8	-0.0074	15A5_15A6	-0.0039	15B6_15B5	-0.0039	
tqs01.Quench.070313182743.141	72	**9630**	19	-0.0064	HcoilHcoil	15A6_15A8	-0.0074	05A3_05A4	-0.0038	08B3_08B4	-0.0035	
tqs01.Quench.070313190544.467	73	**9641**	20	-0.0073	HcoilHcoil	15A6_15A8	-0.0078	15A5_15A6	-0.0045	05A7_05B6	-0.0018	
tqs01.Quench.070313194543.628	74	**9612**	20	-0.0084	HcoilHcoil	15A6_15A8	-0.0087	15A5_15A6	-0.0041	08B5_08A8	-0.0003	
tqs01.Quench.070313202919.217	75	**9926**	20	-0.0071	HcoilHcoil	15A6_15A8	-0.0077	15A5_15A6	-0.0041	05A3_05A4	-0.0018	
tqs01.Quench.070313205845.334	76	**9211**	19	-0.0101	HcoilHcoil	15A6_15A8	-0.0113	15A5_15A6	-0.0045	V1_TrigCvt B2	-0.0003	
tqs01.Quench.070313212139.437	77	**9927**	20	-0.0063	HcoilHcoil	15A6_15A8	-0.0070	15A5_15A6	-0.0029	05B3_05B2	-0.0022	
tqs01.Quench.070313214428.697	78	**9924**	20	-0.0057	HcoilHcoil	15A6_15A8	-0.0066	15A5_15A6	-0.0022	V1_TrigCvt B2	-0.0003	
tqs01.Quench.070314143026.727		**1**	0	-0.1945	WcoilGnd	05B5_05B4	-0.0034	15B5_15B4	-0.0034	08B1_08B2	-0.0032	
tqs01.Quench.070314144411.388	79	**9918**	19	-0.0060	HcoilHcoil	15A6_15A8	-0.0064	15A5_15A6	-0.0022	V1_TrigCvt B2	-0.0001	
tqs01.Quench.070314172755.661	80	**9923**	20	-0.0062	HcoilHcoil	15A6_15A8	-0.0069	15A5_15A6	-0.0024	05B4_05B3	-0.0018	
tqs01.Quench.070314181635.332	81	**9703**	20	-0.0041	HcoilHcoil	15A6_15A8	-0.0046	15A5_15A6	-0.0035	05A2_05A3	-0.0027	
tqs01.Quench.070314184853.444	82	**9989**	20	-0.2071	HcoilHcoil	15A6_15A8	-0.0069	V1_TrigCvtB2	-0.0036	15A5_15A6	-0.0034	
tqs01.Quench.070314194009.492	83	**9983**	20	-0.0035	HcoilHcoil	15A6_15A8	-0.0062	15A5_15A6	-0.0024	05A3_05A4	-0.001	
tqs01.Quench.070314202926.124	84	**9792**	20	-0.0064	HcoilHcoil	15A6_15A8	-0.0067	15A5_15A6	-0.0027	05A4_05A5	-0.0024	
tqs01.Quench.070314205544.003	85	**9982**	20	-0.0046	HcoilHcoil	15A6_15A8	-0.0050	15A5_15A6	-0.0029	05B5_05B4	-0.0013	
tqs01.Quench.070315115603.030	86	**9977**	19	-0.0042	HcoilHcoil	15A6_15A8	-0.0074	15A5_15A6	-0.0053	15A4_15A5	-0.0025	
tqs01.Quench.070315123423.553	87	**9979**	20	-0.0064	HcoilHcoil	15A6_15A8	-0.0074	15A5_15A6	-0.0056	05A1_05A2	-0.0038	
tqs01.Quench.070315130807.526	88	**9925**	20	-0.0091	HcoilHcoil	15A6_15A8	-0.0070	15A5_15A6	-0.0056	15A4_15A5	-0.0025	
tqs01.Quench.070315135406.786	89	**9935**	20	-0.0059	HcoilHcoil	15A6_15A8	-0.0070	15A5_15A6	-0.0057	05A7_05B6	-0.0025	
tqs01.Quench.070315143047.299	90	**9872**	20	-0.0097	HcoilHcoil	15A6_15A8	-0.0098	15A5_15A6	-0.0084	07A1_07A2 M_2	-0.005	
tqs01.Quench.070315153507.444	91	**9770**	20	-0.0134	HcoilHcoil	15A6_15A8	-0.0141	15A5_15A6	-0.0123	07A1_07A2 M_2	-0.0102	
tqs01.Quench.070315183145.732	92	**9487**	20	-0.0136	HcoilHcoil	15A6_15A8	-0.0147	15A5_15A6	-0.0097	08B3_08B4	-0.0073	
tqs01.Quench.070315191243.471	93	**8785**	20	-0.0245	HcoilHcoil	15A6_15A8	-0.0286	15A5_15A6	-0.0190	07B2_07B3	-0.0147	
tqs01.Quench.070315193942.342	94	**8814**	20	-0.0238	HcoilHcoil	15A6_15A8	-0.0244	15A5_15A6	-0.0169	08A3_08A2	-0.0148	
tqs01.Quench.070315200356.056	95	**8819**	20	-0.0262	HcoilHcoil	15A6_15A8	-0.0270	15A5_15A6	-0.0204	08A3_08A2	-0.0144	
tqs01.Quench.070315203136.000	96	**8822**	20	-0.0241	HcoilHcoil	15A6_15A8	-0.0252	15A5_15A6	-0.0179	08B4_08B5	-0.0134	
tqs01.Quench.070315205716.269	97	**8822**	20	-0.0238	HcoilHcoil	15A6_15A8	-0.0252	15A5_15A6	-0.0176	05A5_05A6	-0.0125	

tqs01.Quench.070315213106.928	98	**7148**	20	-0.0489	HcoilHcoil	15A6_15A8	-0.0501	15A5_15A6	-0.0395	08B2_08B3	-0.0148	
tqs01.Quench.070316100850.826	99	**7184**	20	-0.0442	HcoilHcoil	15A6_15A8	-0.0459	15A5_15A6	-0.0346	V1_TrigCvt B2	-0.0001	
tqs01.Quench.070316103450.084	100	**7200**	20	-0.0483	HcoilHcoil	15A6_15A8	-0.0497	15A5_15A6	-0.0396	Q24P_Q24N	-0.0071	
tqs01.Quench.070316110436.334	101	**7207**	20	-0.0451	HcoilHcoil	15A6_15A8	-0.0469	15A5_15A6	-0.0354	V1_TrigCvt B2	-0.0003	

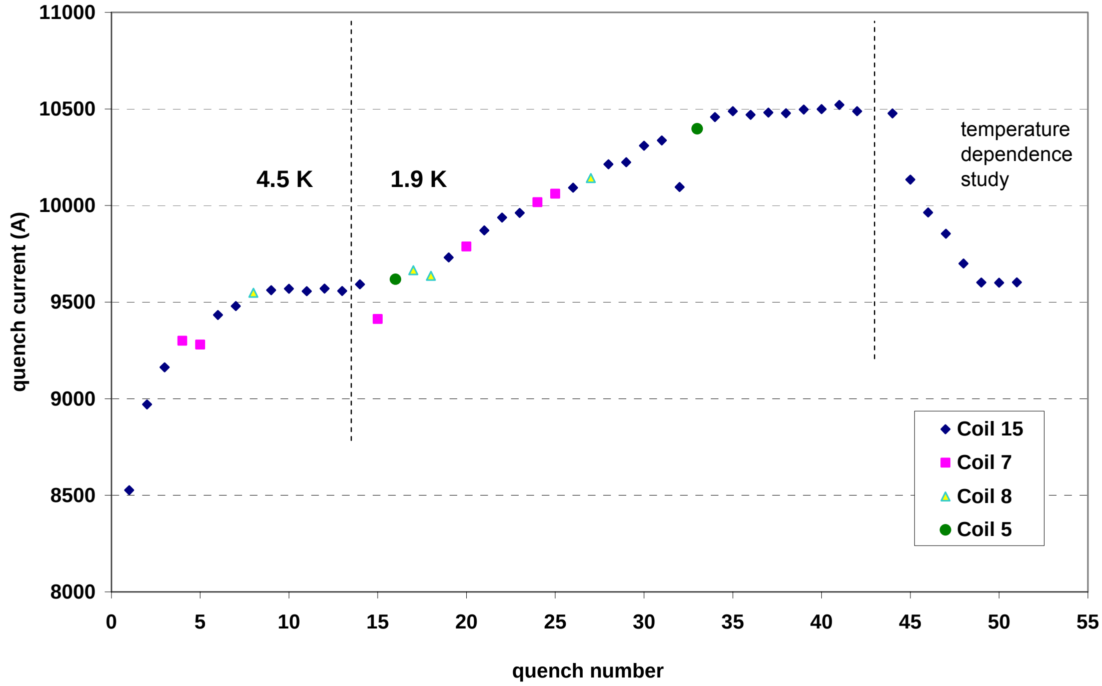


Figure 2.2. Quench history during training at 4.5K, at 1.9K, and during temperature dependence study. The marker of each quench shows the coil where it started.

3. Temperature Dependence

Temperature dependence studies were performed at 20 A/s. All quenches started in coil 15. Results are shown in the following plot.

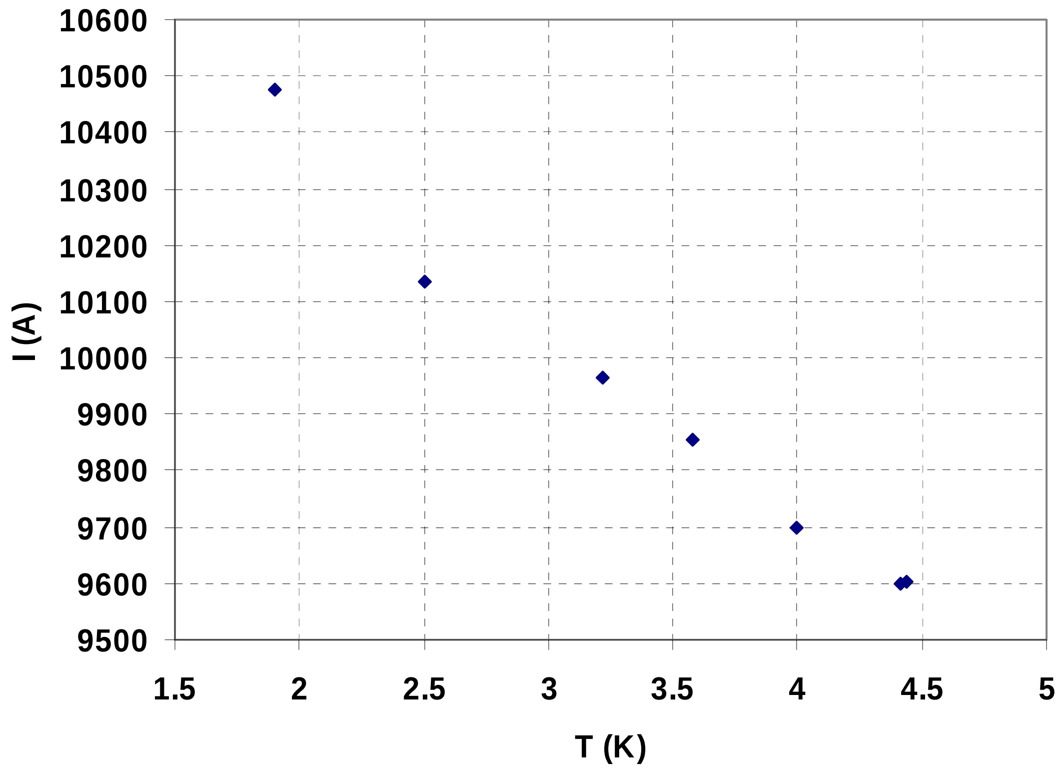


Fig 3.1 Temperature dependence.

4. Ramp Rate Dependence

Ramp rate dependence studies were performed at 4.5 K. Results are shown in the following plot.

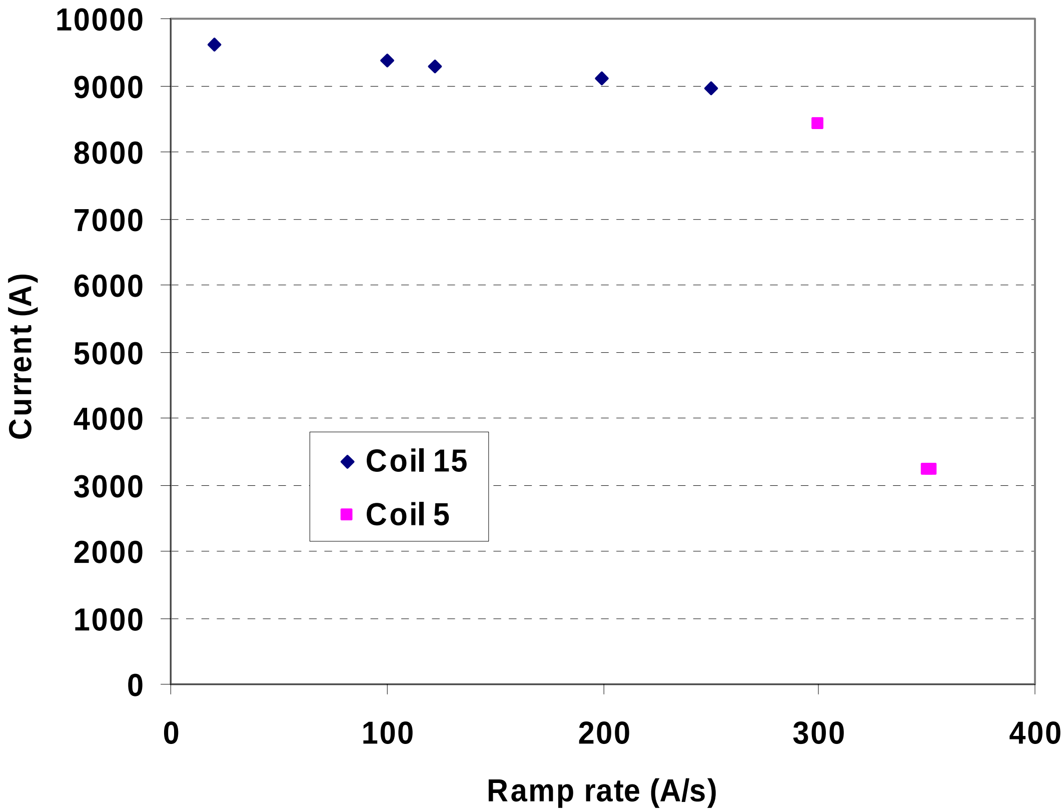


Figure 4.1. Ramp rate dependence of quench current. The marker of each quench shows the coil where it started.

5. Heater studies

Protection heater studies were performed at 4.5 K. Two Heater Firing Units (HFUs) were configured for 4.8mF capacitance, with each connected to two magnet strip heaters in parallel. One HFU was manually fired with the magnet at a constant current to initiate a quench; the second HFU was discharged as a protection heater by the system when the quench was detected. Results for the quench development time are shown in the following plot.

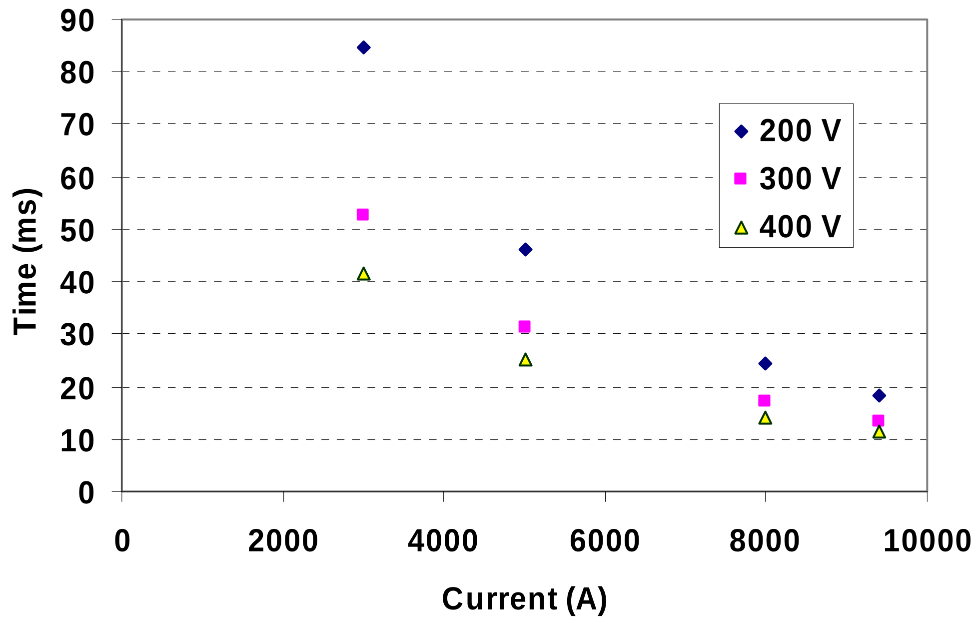


Fig. 5.1 Protection heater delay plus detection time at different current. Different markers show the effect of different capacitor bank voltage.

6. MIITs study

A study aimed at evaluating the effects of high MIITs was performed at 4.5K. The spot heater was not operational, therefore spontaneous quenches were used during this study. In the first part of the test, current ramp rate was set to 250 A/s in order to quench around 9000 A, and the dump delay was increased from 5 ms to 200 ms (following these steps: 25, 45, 65, 90, 200 ms). Standard current ramps at 20 A/s with no dump delay were performed after each MIITs deposition in order to asses any change in magnet performance. After quench 67 it was observed that 200 ms after the quench the current was so low that any further increase of the delay was not going to increase the MIITs (6.87). Therefore the ramp rate was set to 20 A/s for all quenches in the rest of the study.

At 20 A/s the quench current was about 9620 A. The dump delay was increased from 5 to more than 250 ms. With quench 72 we started delaying also to the quench protection heaters following these steps: 7.6, 15.6, 21.2, 27.3 ms. After quench 74 (dump delay: 270 ms, protection heater delay: 21.2 ms, MIITs: 7.95) the quench current jumped to 9926 A (+3.3%).

After quench 75 (dump delay: 276 ms, protection heater delay: 27.3 ms, MIITs: 8.16) the quench current decreased to 9211 A (-7.2% with respect to the previous quench). A following series of three quenches with standard delays (dump delay: 5 ms, no protection heater delay) found a plateau at 9923 A. Quench 80 (dump delay: 280 ms, protection heater delay: 30.7 ms, MIITs: 8.07) caused a small current decrease (9703 A) followed by a new current record (9989 A) in the two subsequent standard quenches. The current reached in quench 82 was 0.6% higher than the previous plateau, and 4.0% higher than the plateau with 20 A/s ramps before the MIITs study (9602 A).

Quench 83 (dump delay: 289 ms, protection heater delay: 40 ms, MIITs: 7.82) caused another small current decrease (9792 A) followed by a plateau around 9980 A. The following series of quenches with further increases of the protection heater delays (finally removed in quench 90) failed to increase the MIITs. Therefore in quench 90 the detection threshold was increase from 700 mV to 3 V (the AQD was actually around 2 V) generating 7.75 MIITs. In quench 91 (at 9770 A) the detection threshold was increased to 4 V (the AQD was actually around 3 V) and the quench generated 8.08 MIITs causing a current degradation of 2.9% with respect to the previous quench. In quench 92 (at 9487 A) the detection threshold was increased to 7 V and the quench generated 8.7 MIITs causing a current degradation of 7.4% with respect to the previous quench. A series of quenches with standard delays found a plateau at 8820 A. Another quench (97) with 7 V threshold without protection heaters and with 300 ms dump delay generated 9.53 MITTs. Finally a series of quenches with standard delays found a plateau at 7200 A (-18.4% with respect to the previous plateau, and -25% with respect to the plateau with 20 A/s ramps before the MIITs study). The results are shown in the following plot.

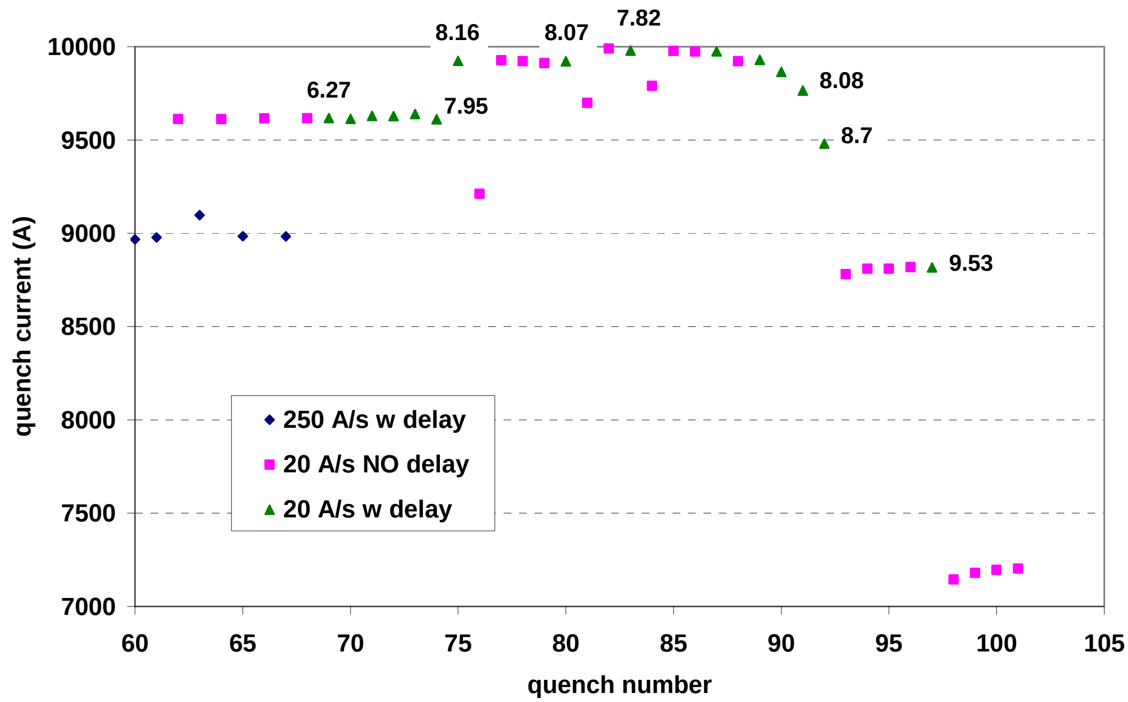


Figure 6.1. Quench history during MIITs study. The marker of each quench shows the kind of quench. The numbers close to some quenches at 20 A/s with delays show the MIITs generated during that quench.

7. Magnetic Measurements

The field quality magnetic measurements were made with the VMTF vertical drive system and LHC/EMS rotating harmonic coil readout cart. Several data sets were captured: warm z-scan before cool down, z-scan at 6.5 kA @ 4.5 K, a full measurement program at 1.9 (described below), and finally a z-scan after the magnet warm up. A 0.1 m long tangential probe, with 2 dipole, 2 quadrupole and 1 tangential windings, was utilized. This probe was specially built for these measurements with a radius of 2.17 cm, optimized to the warm finger ID. The positive direction of the z-axis for the scans is pointing from the magnetic center to the lead end, from which the probe was inserted. Each measurement (e.g., at one z-position) contains data from at least 25 full rotations of the probe, and z-scans steps were equal to the length of the probe.

The magnetic measurement program at 1.9 K consisted of the following measurements:

a. Z-scans at 12.3 Tm/m (LHC injection, estimated to be 0.583 kA), 100 Tm/m (estimated to be 5.15kA), and 200 Tm/m or just below the maximum quench current, I_{qmax}– 0.6kA. For the last measurement, the magnet was powered at 10kA due to the quench limitation around 10.5 kA.

b. Z-scan at 4kA for comparison with TQC01
c. Eddy current loops: 20 40 and 80 A/s up to 10 kA with the probe positioned in the center of the magnet
d. Dynamic effects measurement, which included a current accelerator profile, similar to the one used in LHC MQXB quads (15 min. duration of the injection plateau and the probe positioned in the center of the magnet).

All magnetic measurement results are presented at 17 mm reference radius, the official radius adopted for LHC. A detailed magnetic measurements summary is posted at the following URL:

HTTP://tdserver1.fnal.gov/velev/magnets/web/magnets/TQS01/TQS01c_mag_meas.html

Table 7.1 summarizes the quadrupole strength (T*m/m) and transfer function (TF) versus the excitation current, measured when the probe was positioned at the center of the magnet body (z=0 m). The 16% degradation of the TF at high currents is expected due to the iron saturation.

Fig. 7.1 shows the TF versus z coordinate profiles at 0.58, 5.15 and 10 kA. The integral magnetic lengths are calculated to be 0.712, 0.723 and 0.735 m at these currents.

Requested Current (A)	-10	10	583	4000	5155	10000
Measured Current (A)	-10.81	10.80	583.84	3997.74	5152.42E	9995.80
Field (T*m/m)	0.2336	0.2336	12.48	83.92	104.58	184.92
TF (T/kA)	21.71	21.62	21.38	20.99	20.29	18.50

Table 7.1 Strength and TF at different currents in the body of the magnet

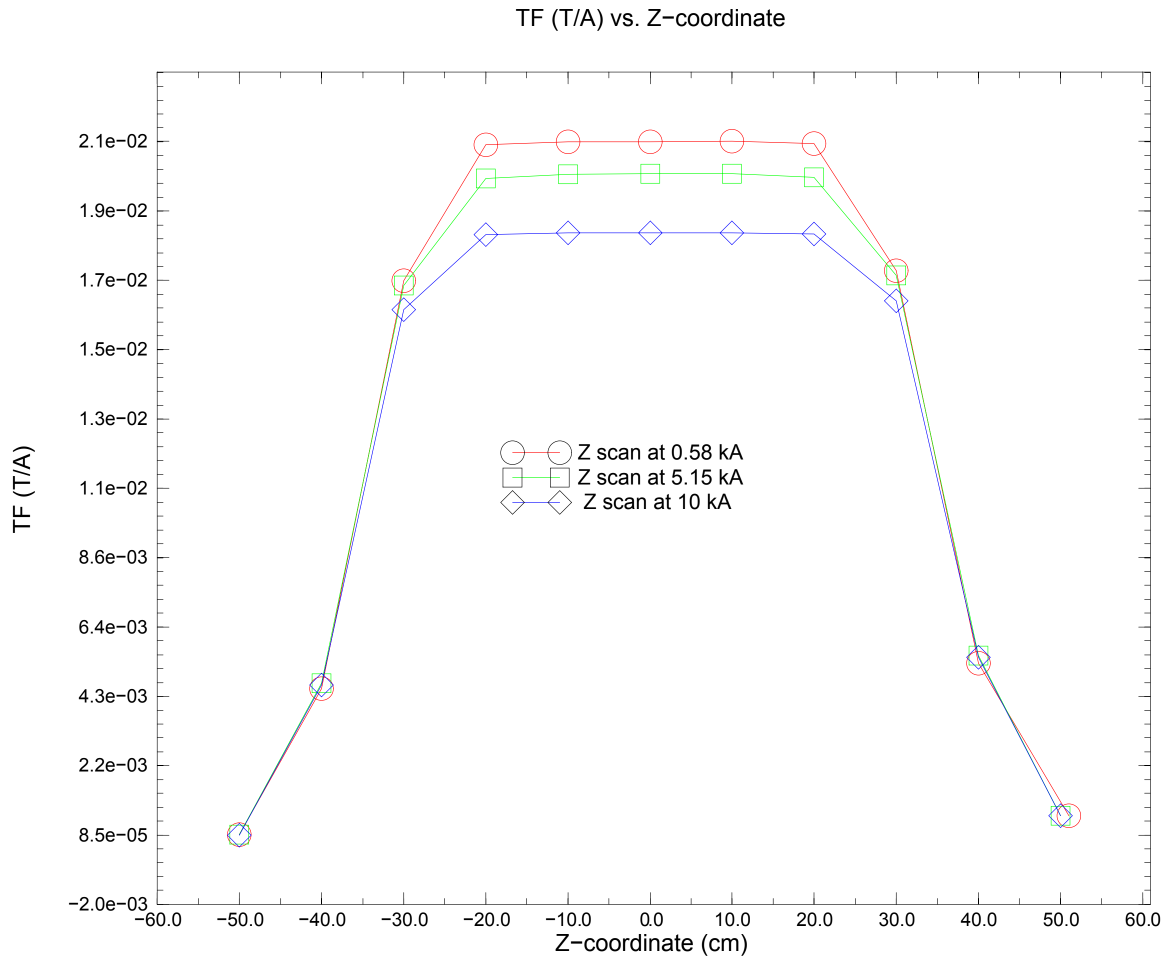


Figure 7.1. The magnet TF versus z coordinate at 0.583, 5.15 and 10.0 kA.

Table 7.2 summarizes the harmonics at injection (0.583 kA) and maximum measured current (10 kA), averaged over the magnet (left) and for the center body position (right). In general, the field harmonics are in the order of several units. The b_5 and b_6 at injection are observed to be relatively large, ~ 10 units.

Table 7.2. TQS01c body and average harmonics at different currents

Multipole(units)	Average Injection	Average 10 kA	Body only Injection	Body only 10kA
b_3	-1.014	-0.365	-1.147	-0.805
b_4	-3.726	-0.028	-3.313	0.057
b_5	-9.054	1.636	-9.263	1.481
b_6	-10.667	1.505	-10.755	1.480
b_7	0.108	0.014	0.103	0.024
b_8	0.080	-0.012	0.076	0.000
b_9	0.134	-0.021	0.155	-0.004
b_10	0.093	-0.013	0.117	0.000

a_3	0.085	0.298	1.358	1.560
a_4	-4.076	-1.037	-4.880	-1.341
a_5	-4.122	0.329	-4.565	0.466
a_6	0.422	0.041	0.119	-0.126
a_7	-0.077	-0.041	-0.031	-0.040
a_8	-0.018	-0.040	0.031	-0.040
a_9	0.014	-0.007	0.038	-0.003
a_10	-0.015	0.003	-0.009	0.000

Figure 7.2 shows the dodecapole versus time. The current profile used in this measurement was derived from the profile of production inner triplet LHC quadrupole (LQXB) measurements. The duration of the injection porch was set to 15 min at 12.8 T, accordingly to the LHC specifications. One can observe that *the b6 decay and snapback*, which are commonly observed in NbTi magnets, *are not present* (see the time interval from ~900 to ~1800 s).

Current loops at 20, 40 and 80 A/s for TQS01 quadrupole have been executed. The b_6 difference between the ramp rate loops is small, indicating small or negligible eddy current effect on the hysteresis loop. The b_6 hysteresis loops are shown in Figure 7.3.

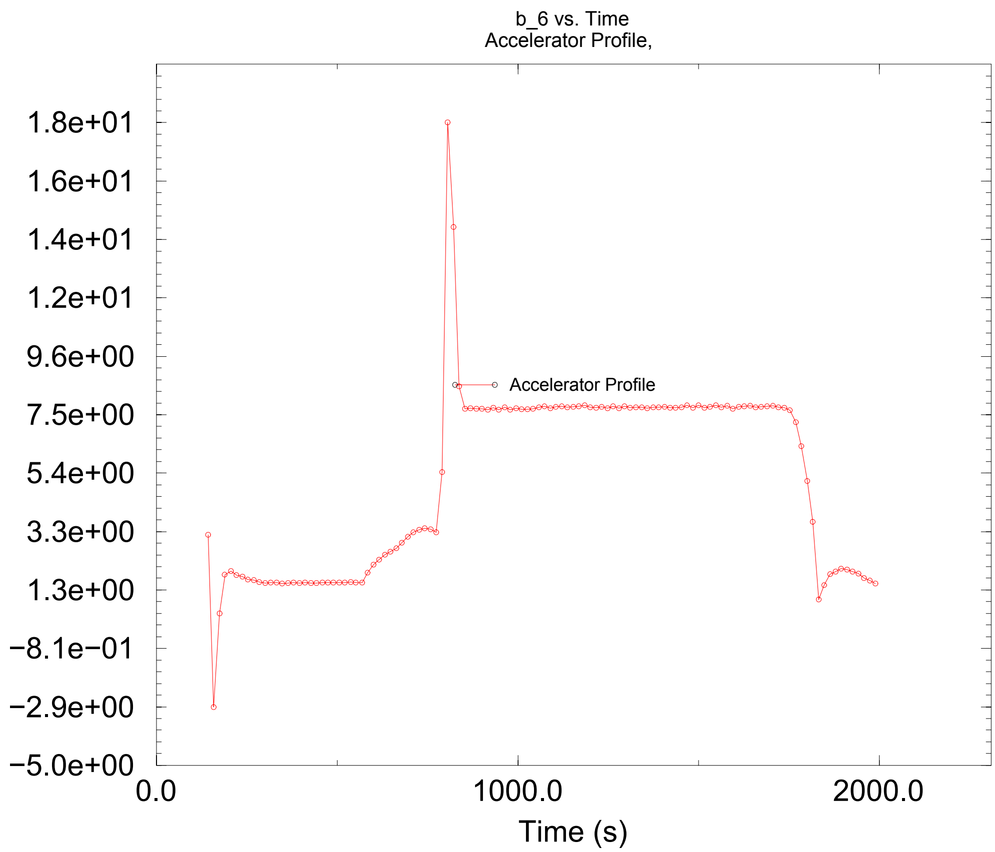


Figure 7.2. Dodecapole (b_6, in units) versus time (s) in a modified LHC accelerator current profile.

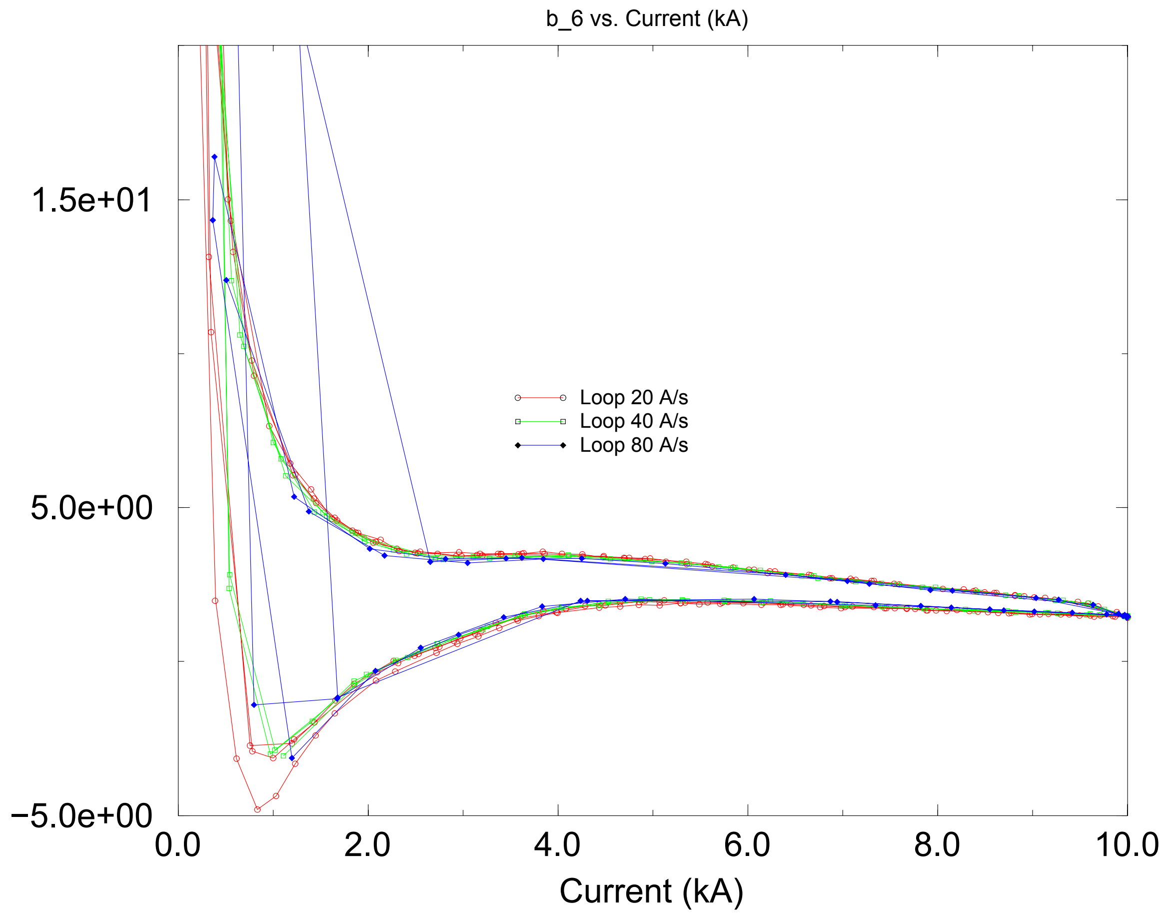


Figure 7.3. Dodecapole (b_6) versus excitation current at different ramp rates: 20 (red), 40 (green) and 80 (blue) A/s.

8. Strain gauge results

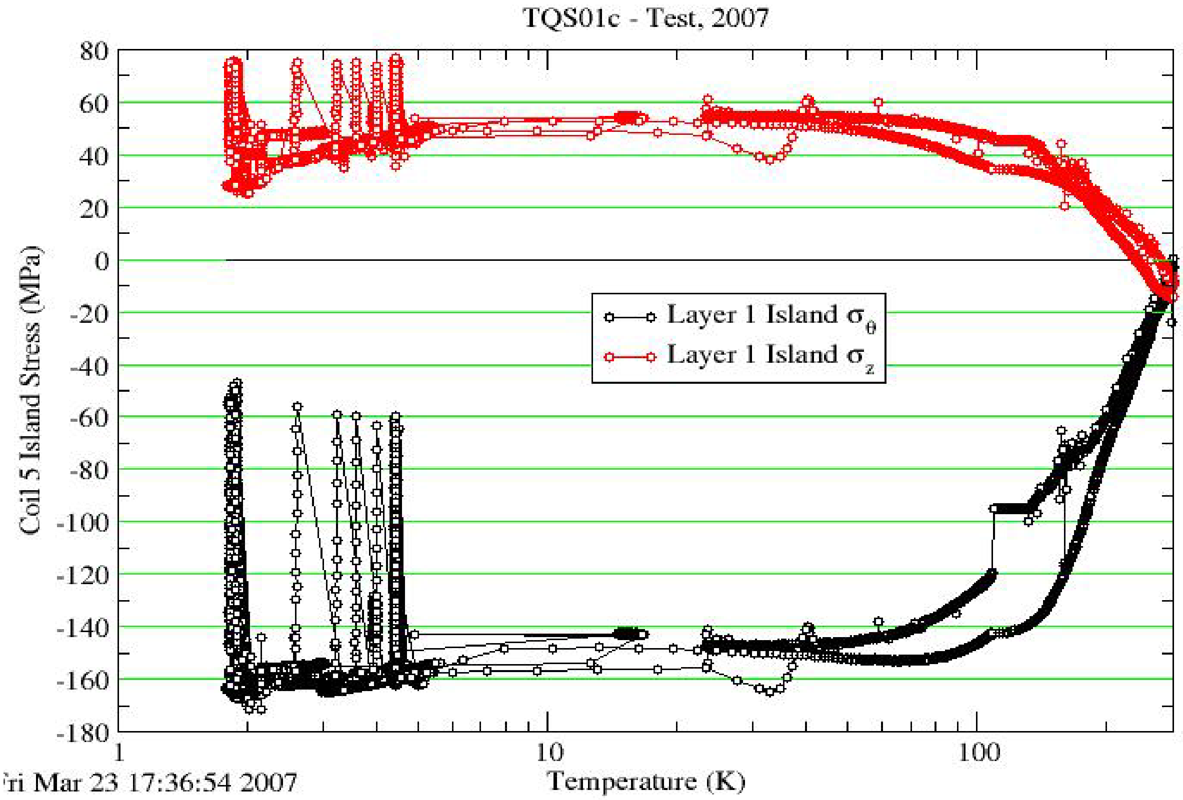
Coils 5,7,8,15 were used in TQS01c. Each coil had 3 strain gauges: two gauges were located on the island center to measure azimuthal and axial strain and a single axial gauge was placed near the lead end. The gauges where thermally compensated by gauges mounted on stress-free element. Fully compensated strain gauges were also used on the shell and the axial tie rods. Measured strain "ε" in two principal directions "z, θ" (and no shear) was converted into stress "σ" using the relationships below with the Modulus, and Poisson ratio for bronze (islands) and aluminum (shell):

$$\sigma_\theta = \frac{E}{(1-\nu^2)}(\varepsilon_\theta + \nu\varepsilon_z) \quad \sigma_z = \frac{E}{(1-\nu^2)}(\varepsilon_z + \nu\varepsilon_\theta)\,.$$

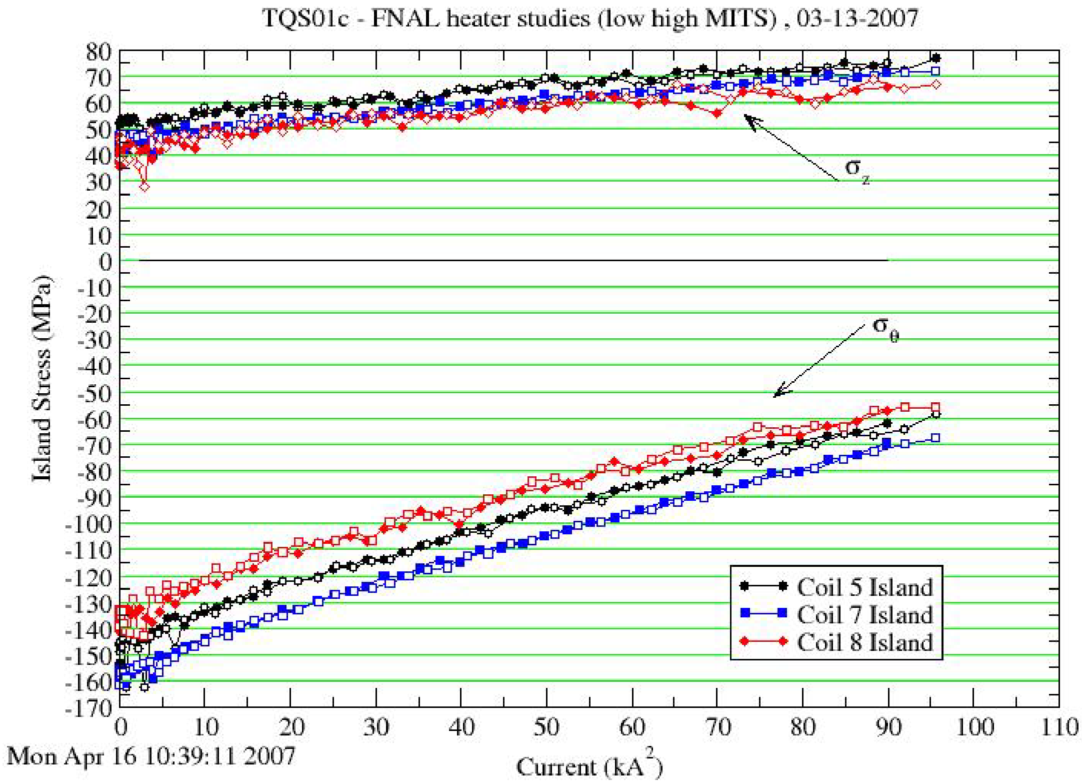
A comparison of stress in the structure and coils between the three TQS01 assemblies is shown in the table below.

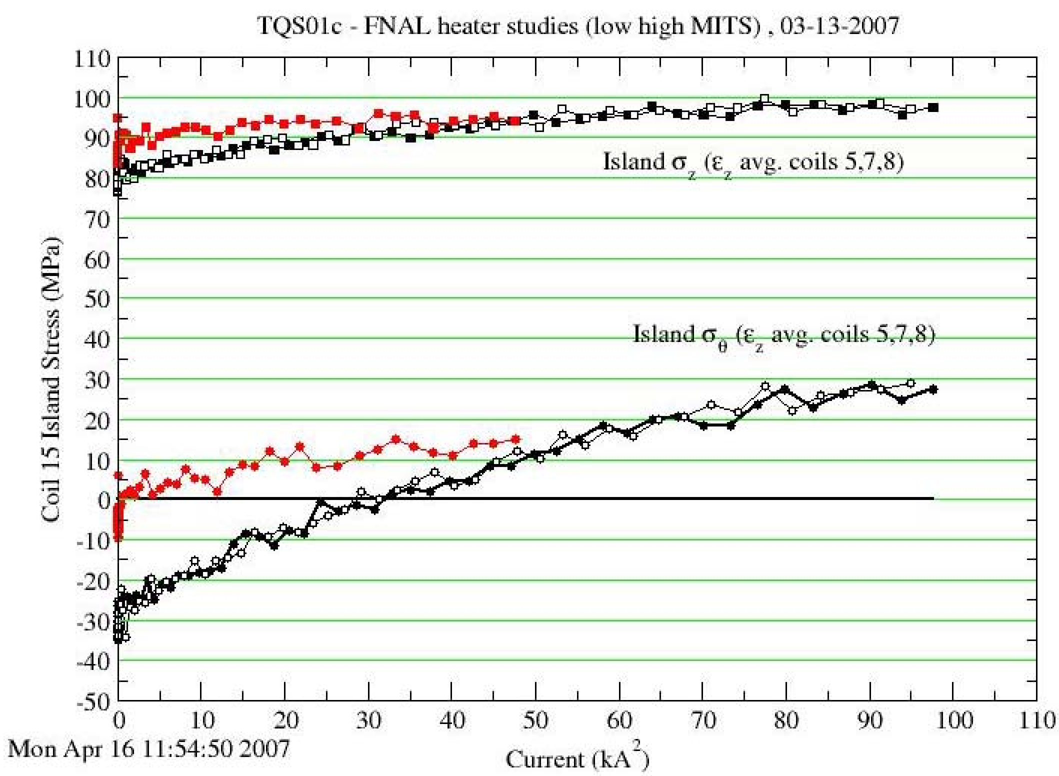
	TQS01	TQS01b	TQS01c
Maximum current (A)	10602 (4.4K) 11019 (3.2K)	9932 (4.4K)	9570 (4.4K) 10521(1.9K) 9989 (4.4K)
Iss (%)	87% (4.4K)	82% (4.4K)	80-82% (4.4K) 80% (1.9K)
Shell cold (MPa) -t	+152	+158	+142
Shell cold (MPa) -z	+143	+140	+137
Rods cold (MPa) -z	+113	+116	+148
Island cold (MPa) -t	-198	-202	-162
Island cold (MPa) -z	+34	+34	+39

A typical measured stress of coil 5 during cool-down is shown in the figure below:

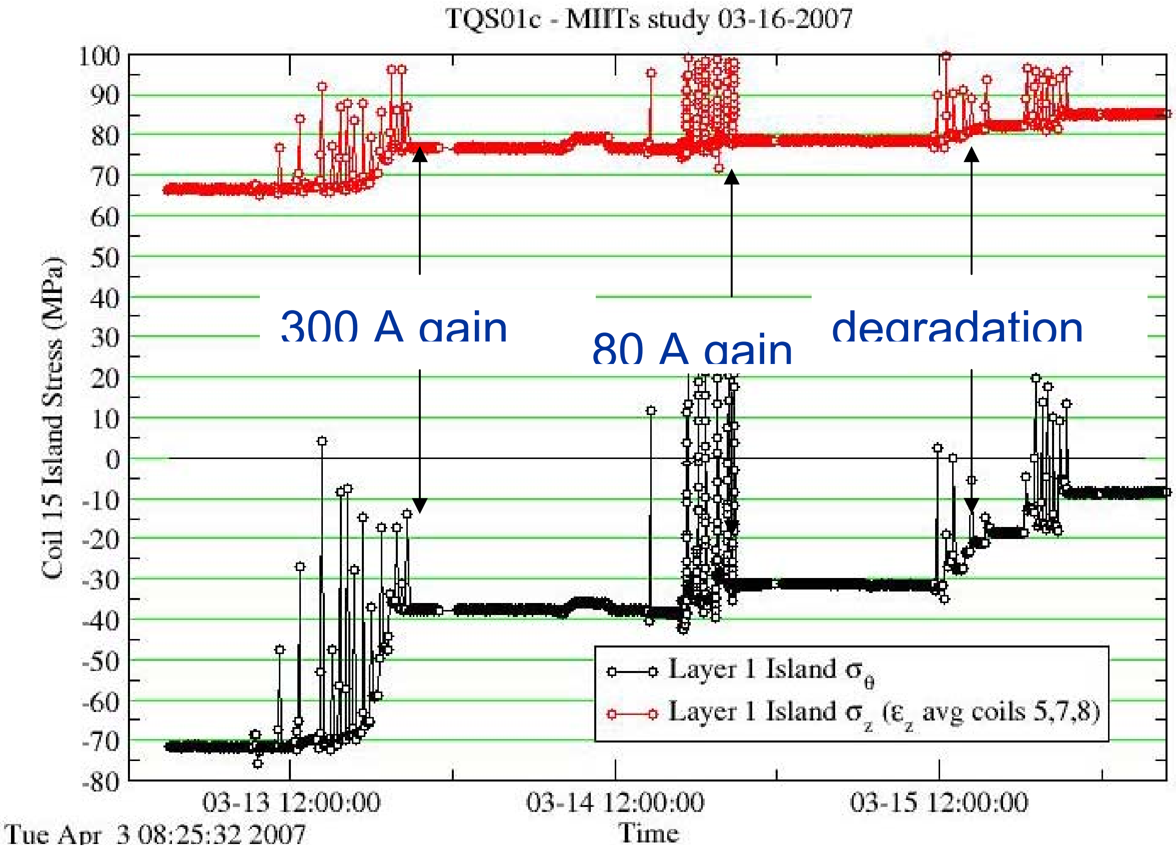


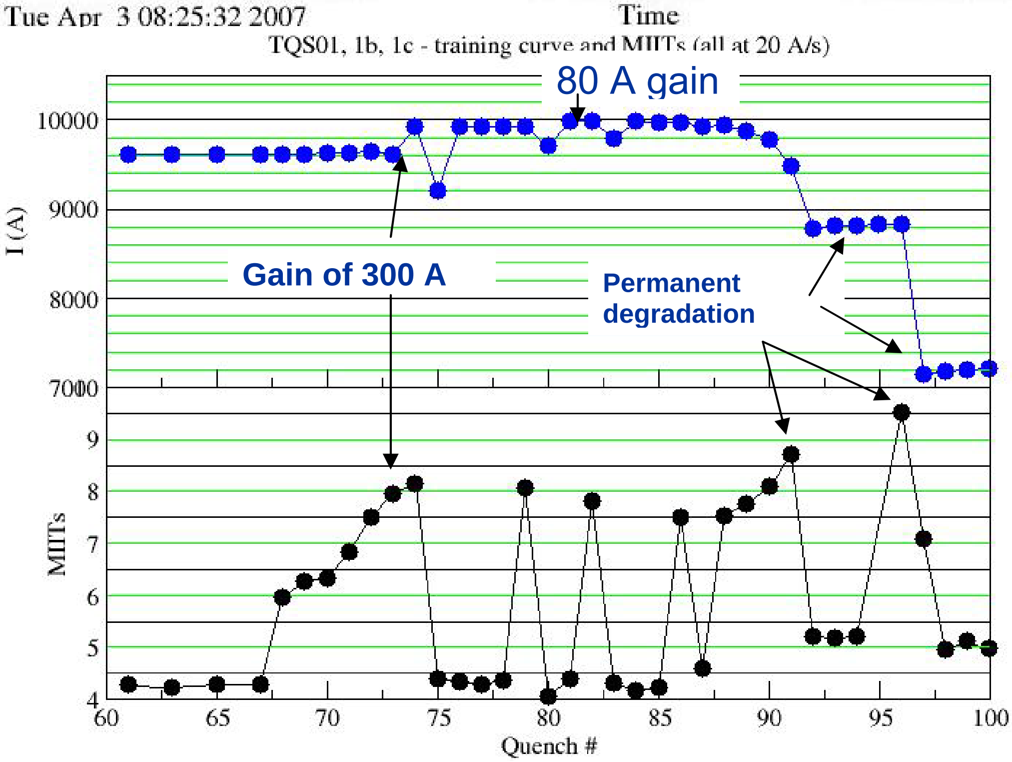
Coils 7 and 8 showed a similar behavior however coil 15 behaved differently. During cool-down coil 15 gained only half the expected pre-stress and during heater studies lost most of its remaining pre-stress. In fact all indications are that the coil ended up in azimuthal tension close to 30MPa at 10kA. The figures below show the stress in all coils during excitation:


TQS01c - FNAL heater studies (low high MITS) , 03-13-2007
Island Stress (MPa)
Current (kA^2)
Mon Apr 16 10:39:11 2007
σz
σθ
Coil 5 Island
Coil 7 Island
Coil 8 Island


TQS01c - FNAL heater studies (low high MITS) , 03-13-2007
Coil 15 Island Stress (MPa)
Current (kA^2)
Mon Apr 16 11:54:50 2007
Island σz (εz avg. coils 5,7,8)
Island σθ (εz avg. coils 5,7,8)

Changes in coil 15 island stress during heater studies (see section 6). After the coil generated 8 MIITs it gained 300A with an additional 80A following. Increasing the MIITs level closer to 9 MIITs resulted in coil degradation.

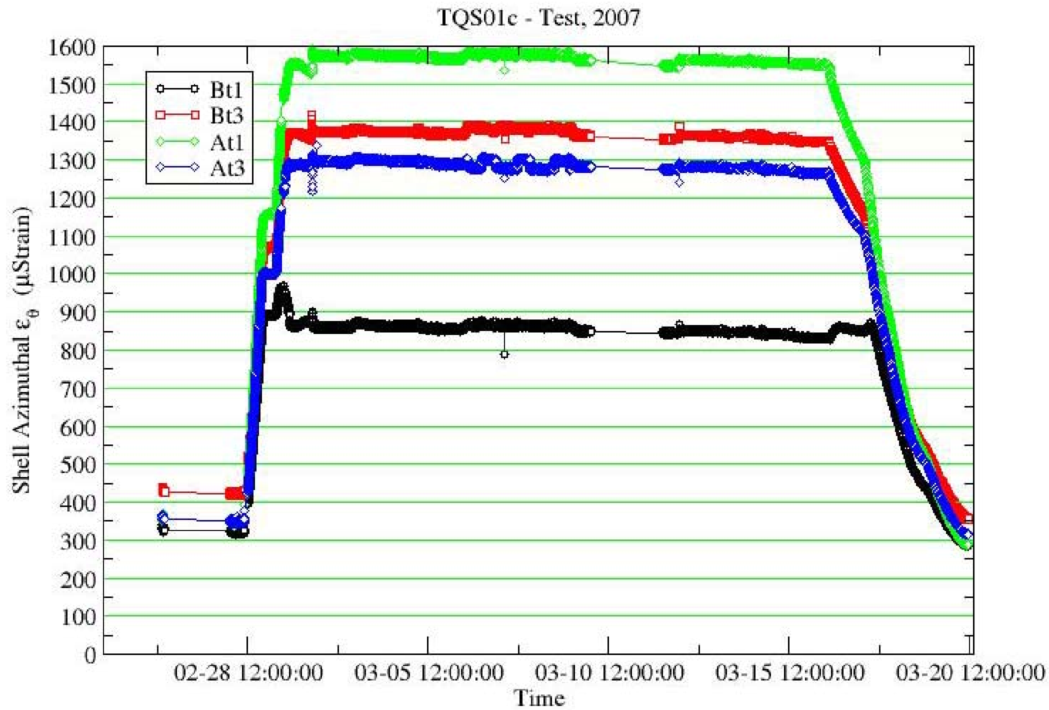


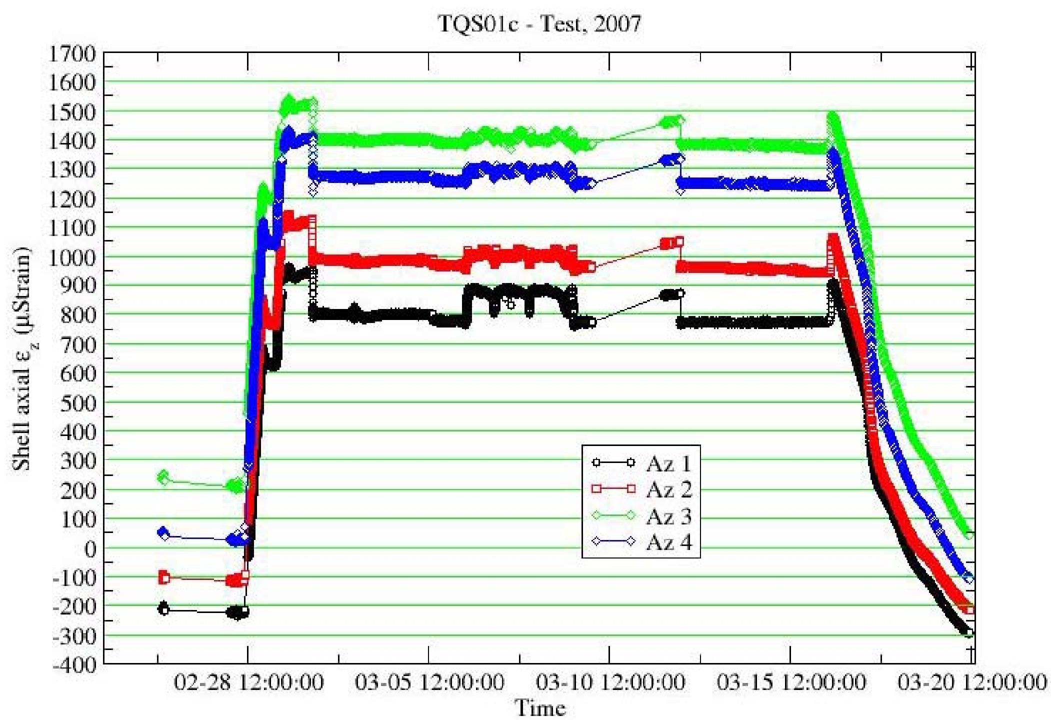


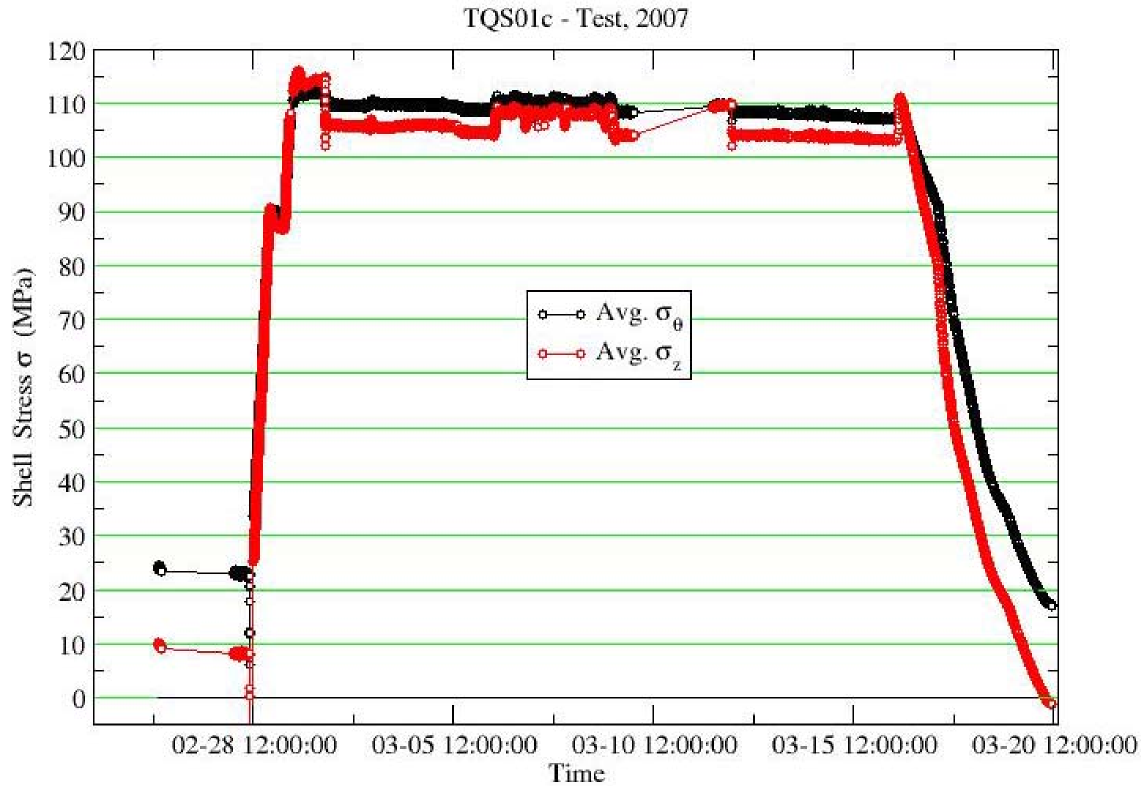
A number of pdf plot files with strain data can be found in:

http://supercon.lbl.gov/caspi/download/TQS01/TQS01c/

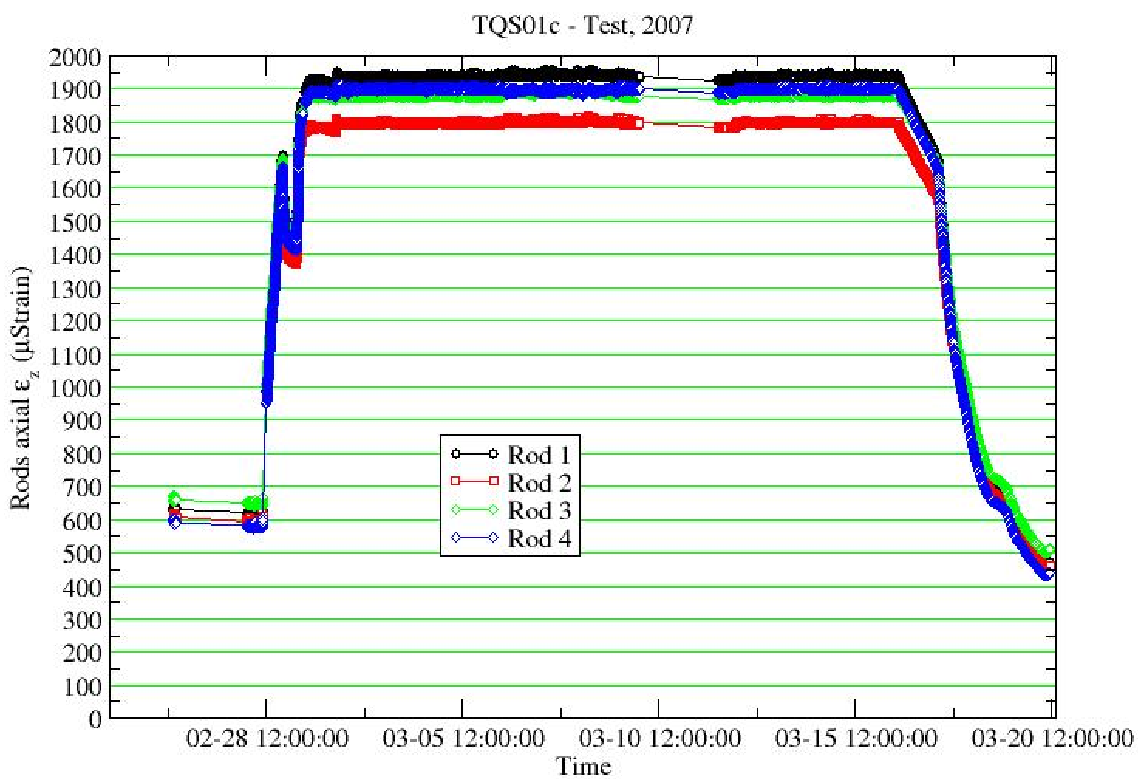
The measured strain during the entire test is shown in the following figures:



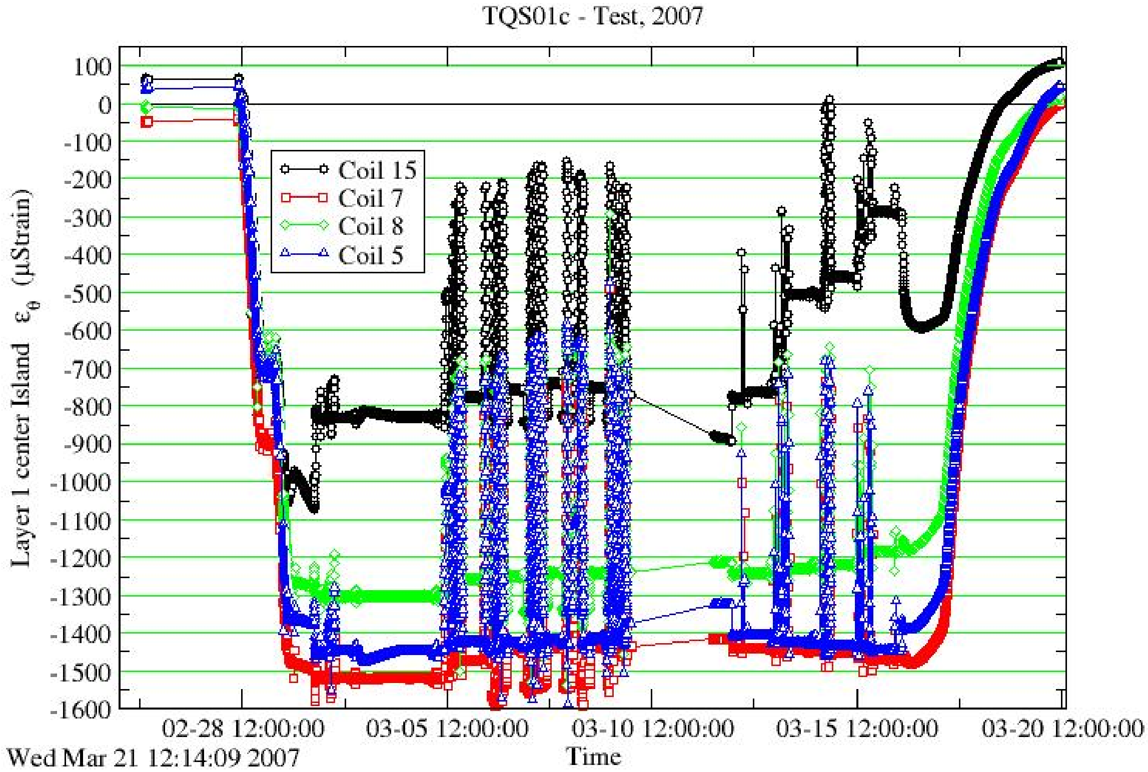


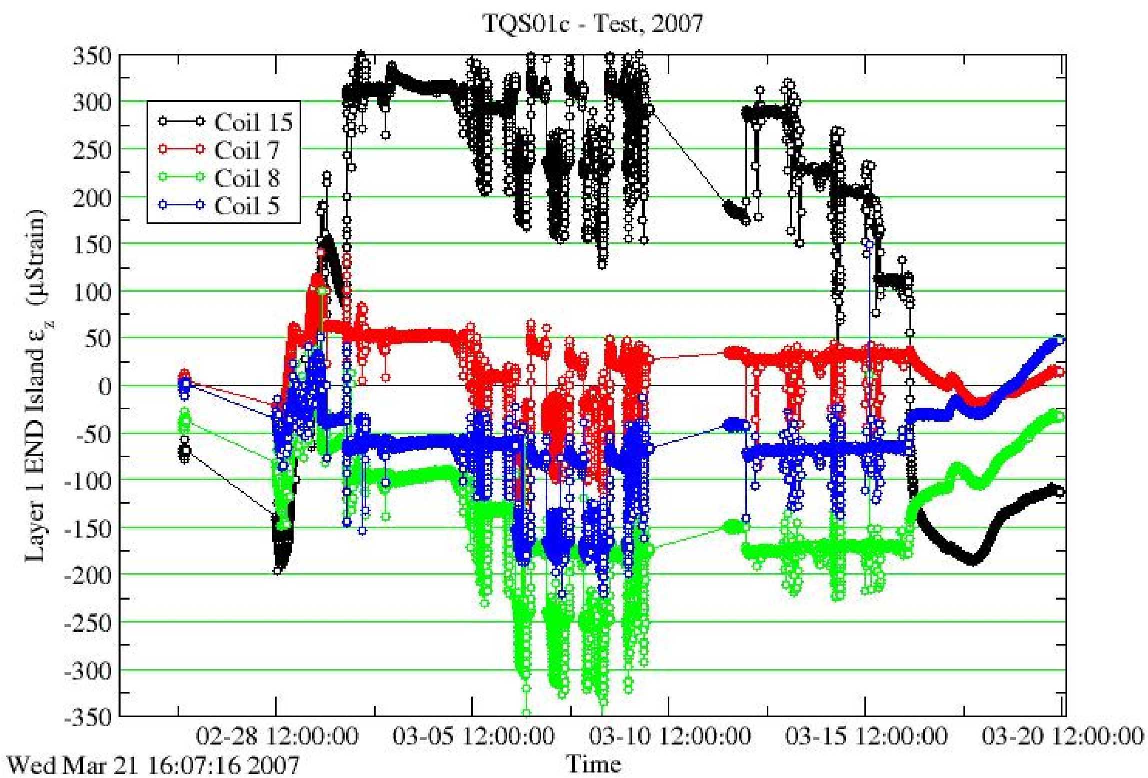


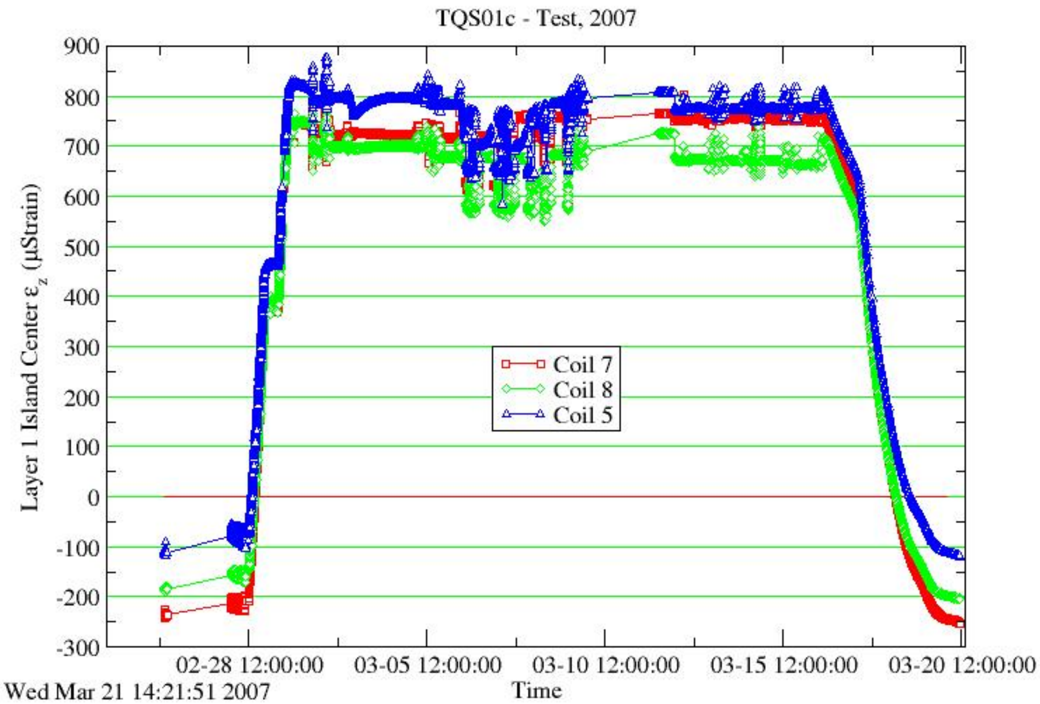
TQS01c - Test, 2007
Shell Stress σ (MPa)
Avg. σ_θ
Avg. σ_z
Time
02-28 12:00:00
03-05 12:00:00
03-10 12:00:00
03-15 12:00:00
03-20 12:00:00

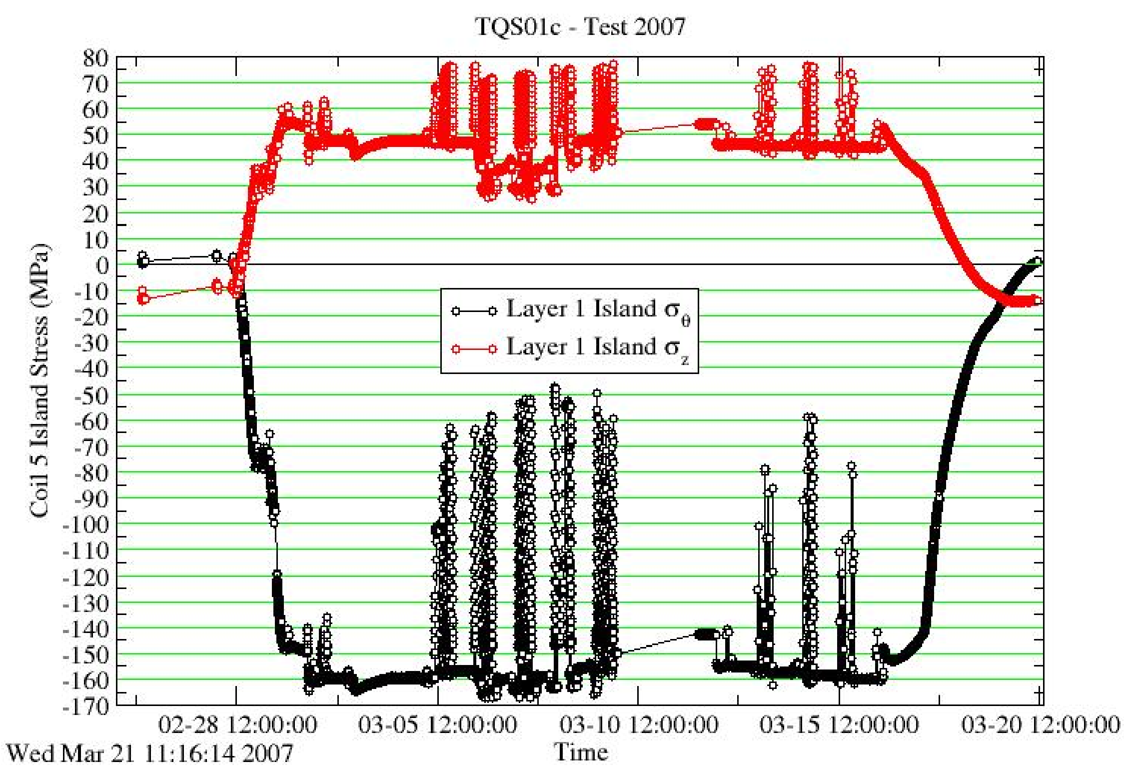


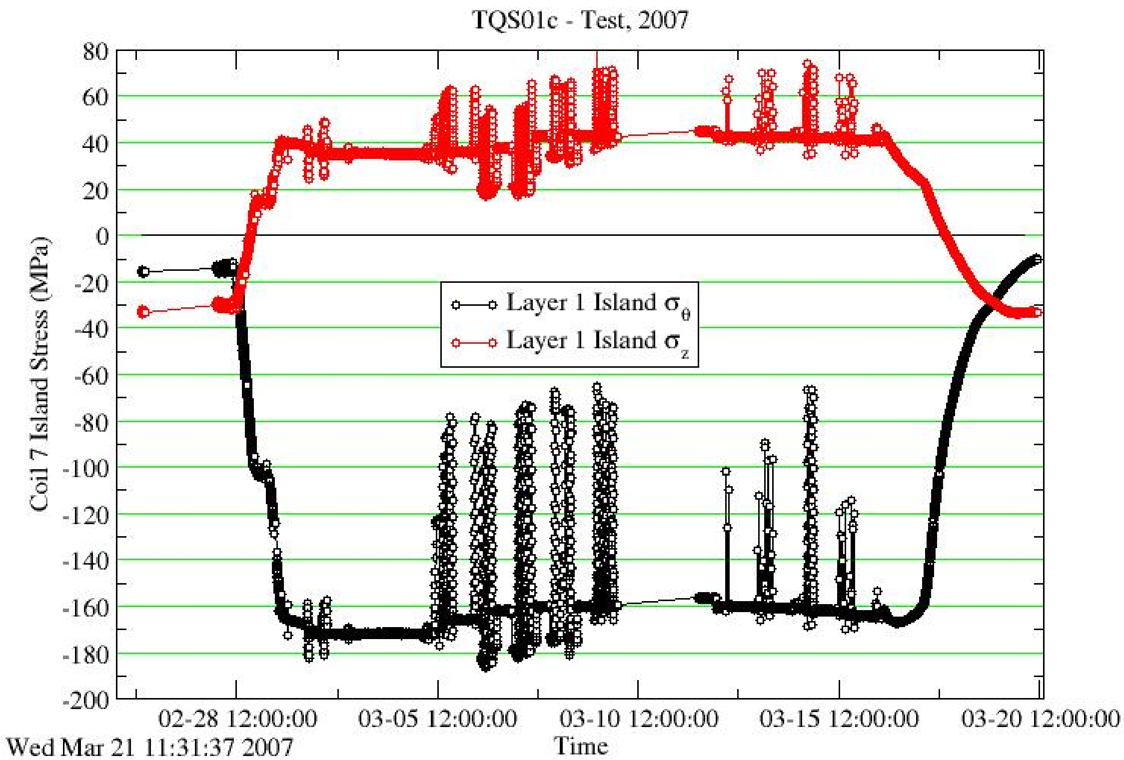
TQS01c - Test, 2007
Rods axial ε_z (μStrain)
Rod 1
Rod 2
Rod 3
Rod 4
Time
02-28 12:00:00
03-05 12:00:00
03-10 12:00:00
03-15 12:00:00
03-20 12:00:00

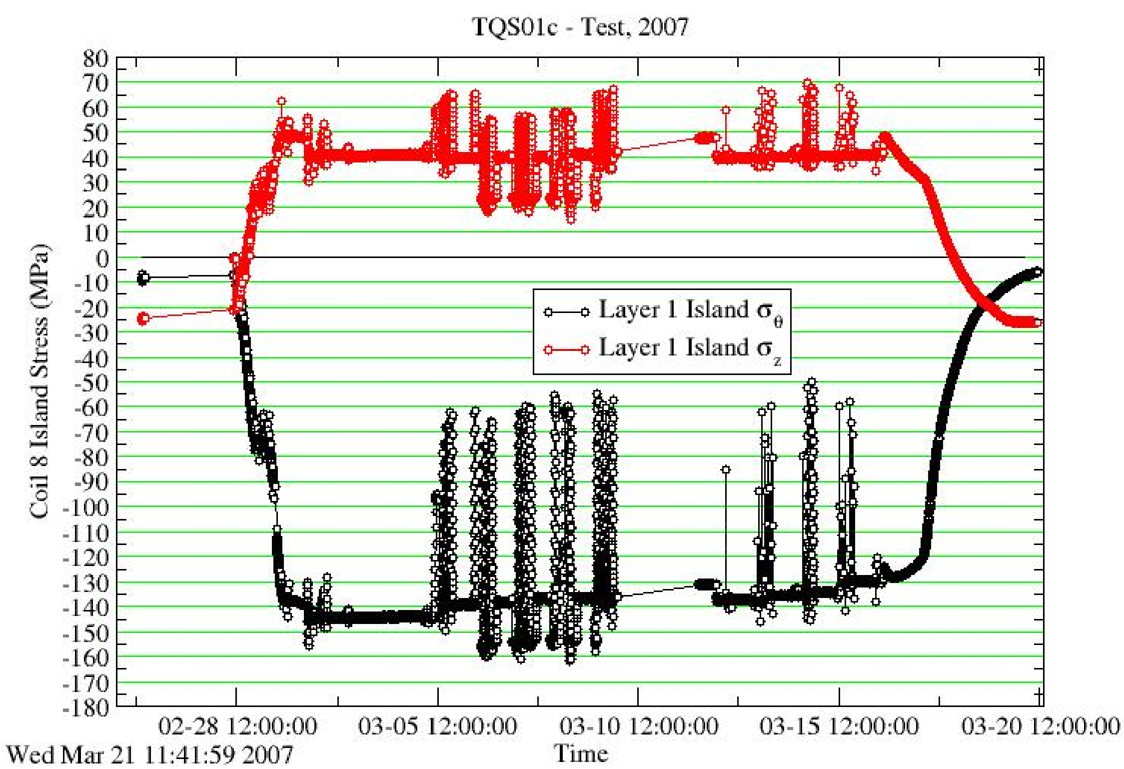

TQS01c - Test, 2007
Layer 1 center Island ε_θ (µStrain)
Coil 15
Coil 7
Coil 8
Coil 5
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400
-1500
-1600
02-28 12:00:00
03-05 12:00:00
03-10 12:00:00
03-15 12:00:00
03-20 12:00:00
Time
Wed Mar 21 12:14:09 2007

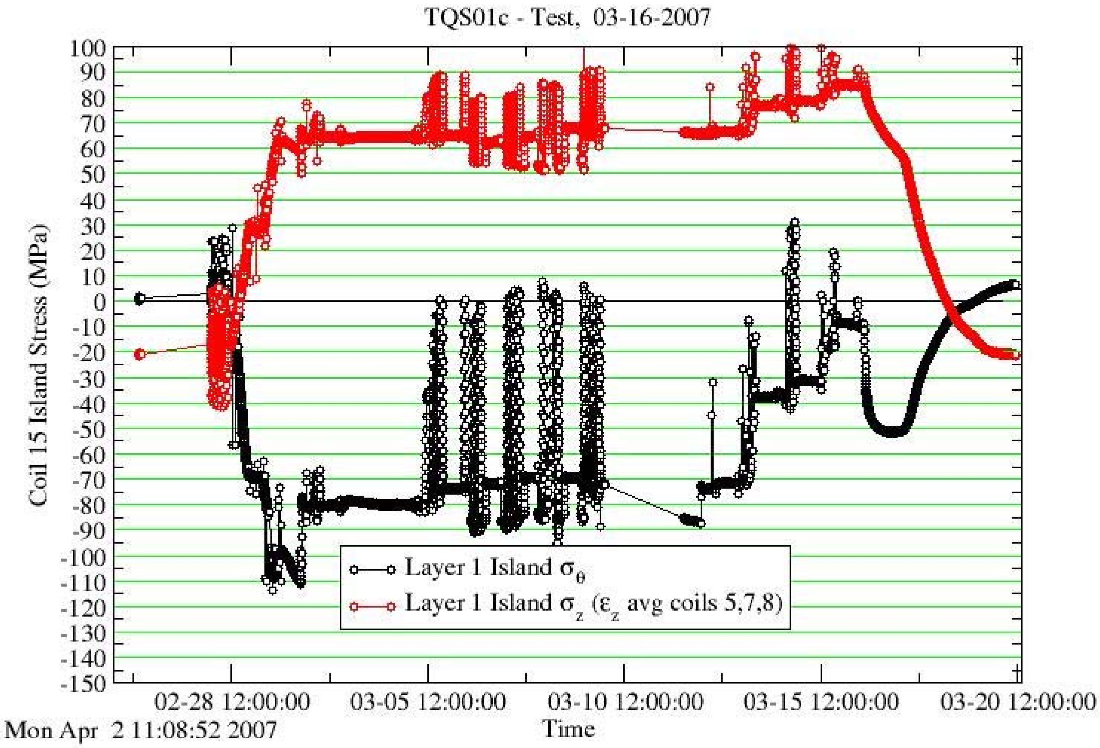

TQS01c - Test, 2007
Layer 1 END Island ε_z (µStrain)
Coil 15
Coil 7
Coil 8
Coil 5
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
02-28 12:00:00
03-05 12:00:00
03-10 12:00:00
03-15 12:00:00
03-20 12:00:00
Time
Wed Mar 21 16:07:16 2007

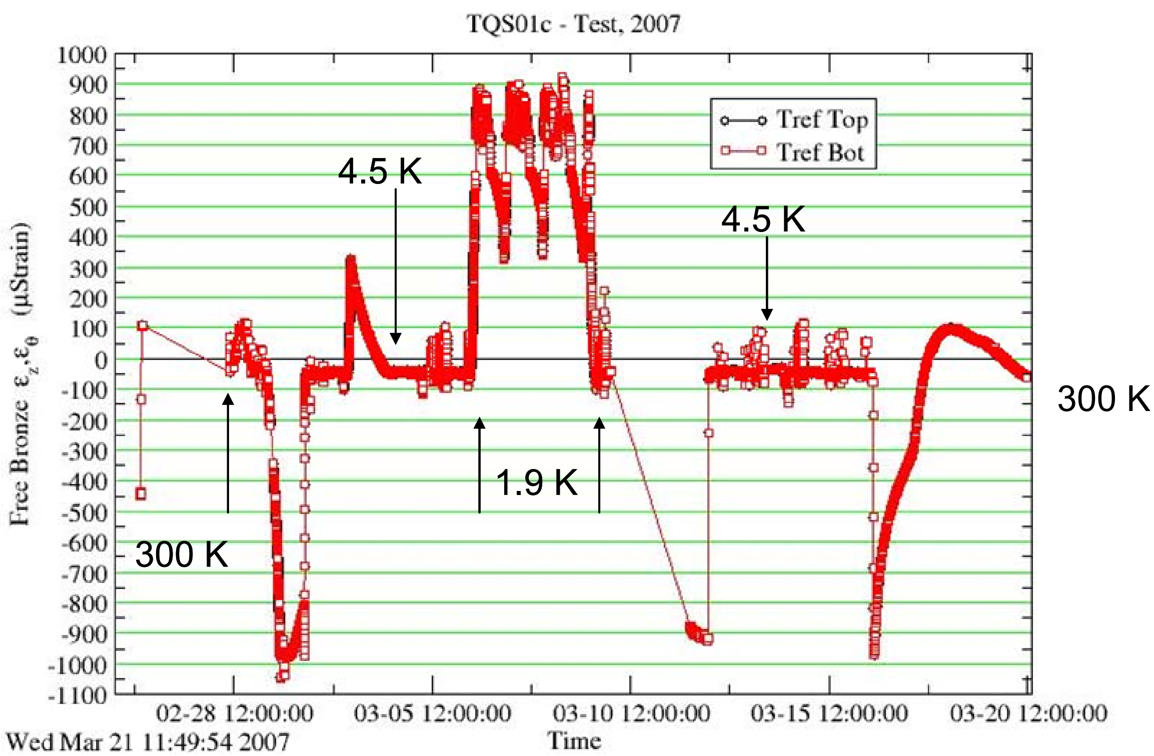

TQS01c - Test, 2007
Layer 1 Island Center ε_z (µStrain)
Coil 7
Coil 8
Coil 5
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
02-28 12:00:00
03-05 12:00:00
03-10 12:00:00
03-15 12:00:00
03-20 12:00:00
Time
Wed Mar 21 14:21:51 2007


TQS01c - Test 2007
Coil 5 Island Stress (MPa)
Layer 1 Island σ_θ
Layer 1 Island σ_z
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
02-28 12:00:00
03-05 12:00:00
03-10 12:00:00
03-15 12:00:00
03-20 12:00:00
Time
Wed Mar 21 11:16:14 2007


TQS01c - Test, 2007
Coil 7 Island Stress (MPa)
Layer 1 Island σ_θ
Layer 1 Island σ_z
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
02-28 12:00:00
03-05 12:00:00
03-10 12:00:00
03-15 12:00:00
03-20 12:00:00
Time
Wed Mar 21 11:31:37 2007


TQS01c - Test, 2007
Coil 8 Island Stress (MPa)
Layer 1 Island σ_θ
Layer 1 Island σ_z
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
02-28 12:00:00
03-05 12:00:00
03-10 12:00:00
03-15 12:00:00
03-20 12:00:00
Time
Wed Mar 21 11:41:59 2007


TQS01c - Test, 03-16-2007
Coil 15 Island Stress (MPa)
Layer 1 Island σ_θ
Layer 1 Island σ_z (ϵ_z avg coils 5,7,8)
02-28 12:00:00
03-05 12:00:00
03-10 12:00:00
03-15 12:00:00
03-20 12:00:00
Time
Mon Apr 2 11:08:52 2007


TQS01c - Test, 2007
Free Bronze $\epsilon_z, \epsilon_\theta$ (μStrain)
Tref Top
Tref Bot
4.5 K
4.5 K
1.9 K
300 K
300 K
02-28 12:00:00
03-05 12:00:00
03-10 12:00:00
03-15 12:00:00
03-20 12:00:00
Time
Wed Mar 21 11:49:54 2007

9. Quench Antenna Data

A quench antenna was used during training at 4.5 and 1.9K. The “KEK/HGQ” quench antenna consists of three stationary coil segments, each 0.35 m long and separated by 0.105 m long couplings. Each coil is made with four windings that are sensitive to normal and skew sextupole and octupole magnetic flux changes, at a radius of 23 mm. The probe was positioned in the bore of the magnet so that the second antenna coil, C2, was centered on the magnet coil center. Data analysis showed that only windings in C2 recorded flux change signals when the magnet started quenching. Figure 9.1 shows for every training quench the difference between the time of the first signal in the quench antenna coils and the time of the quench start according to voltage taps data. This difference is within +3 -2 ms with very few exceptions. Therefore almost all training quenches started in the magnet body and did not propagate to the ends before heater and dump were fired after (usually fast) quench development and detection.

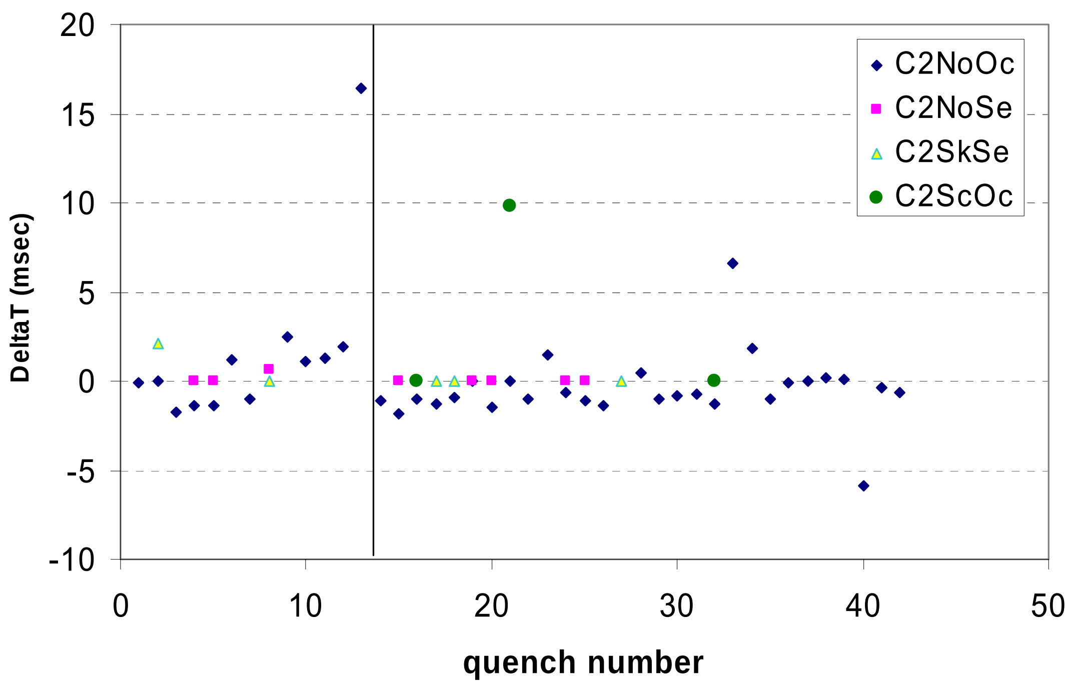


Figure 9.1 Difference between start of signal in quench antenna coils, and in voltage taps during training.

10. RRR measurement

Estimates of RRR in TQS01 coil segments have been made using data captured during the initial cool down of the magnet. This was the first attempt to perform a “slow” cool down of VMTF using gaseous helium, to limit temperature variations across the magnet in order to prevent large coil stresses, and the new procedure worked well. The magnet was cooled with helium gas starting from 300 K at about 09:30 on 2/28, reaching 23 K about 1800 on 3/1/07, as shown in Figure RRR-1; the dewar was filled with liquid helium early on 3/2. No attempt was made to measure coil voltages during warm-up, as has been the usual procedure for VMTF magnet tests.

During the cool down, coil voltages across “fixed” and “configurable” voltage tap segments were monitored by the pentek data loggers, while a current of slowly alternating polarity, +/- 6A, was put through the magnet. However, in fact, the cool down was begun about two hours prior to starting the voltage tap scans, so temperatures had already fallen somewhat by the time voltage monitoring began: thus, “room temperature” voltage readings are somewhat under-estimated because of this. The scan configuration was also not completely correct, as debugging of the new configuration tool was taking place at this time: segments that were manually bridged across “open” taps were incorrect, and therefore are not available during for RRR measurements. At 1800 on 3/1, at 23 K, an attempt was made to correct some of the errors in gain and channel assignments. No attempt was made to cool below this temperature before filling with liquid helium. Thus, in this discussion “RRR” of a segment refers to the ratio of voltage at “about 280 K” (12:20 on 2/28) to that at “about 23 K” (about 18:00 on 3/1) – i.e., it is an approximate measure that is not a proper calculation of RRR. It is possible there were some variations in coil temperatures in the “300 K” data, between inner and outer coils for example. Amplifier gains for the channels studied were correct and stable throughout the measurement.

The best measurements come from the configurable voltage tap (CVT) channels, in which the amplifier gain (or attenuation) is almost continuously adjustable (.001 to 4000) and is therefore optimized for known segment lengths. Fixed voltage taps (FVT) suffer from the use of older (partially programmable) amplifiers with much coarser gain and attenuation settings: in most of the FVT segments at 23 K the voltage difference (from + to -6A) toggles at the 1 bit resolution limit, so the measurements are not very reliable. The CVT segments, however, have very good resolution in most cases.

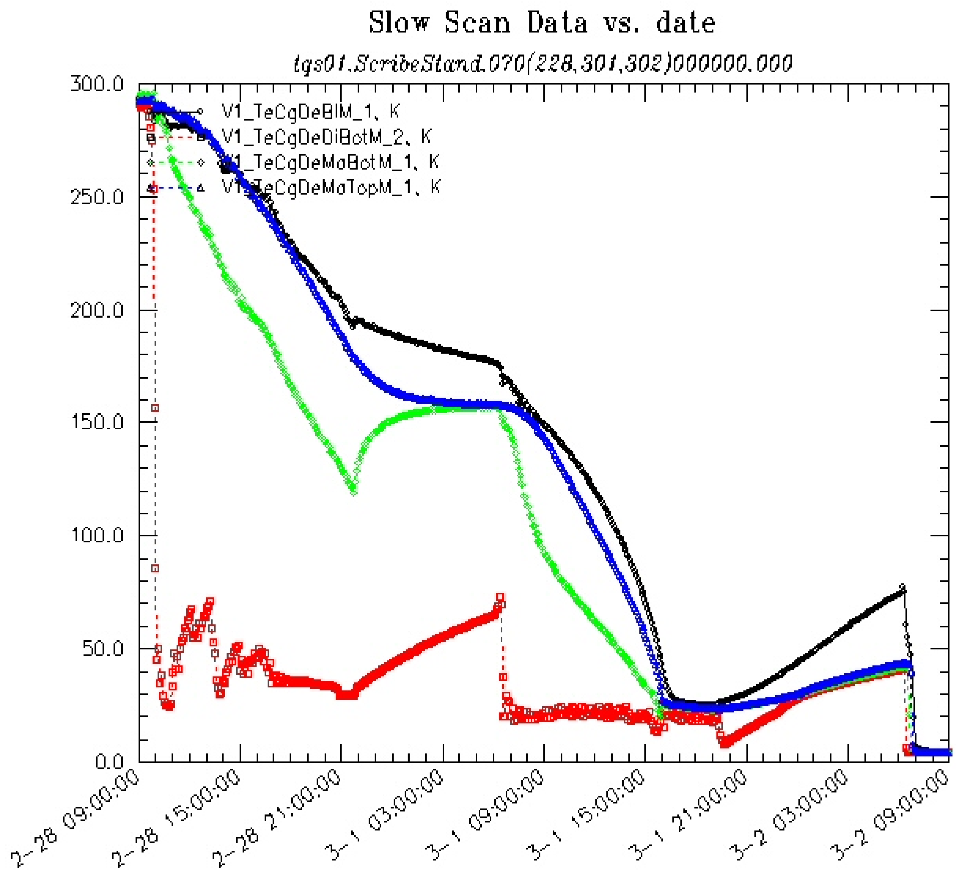


Figure 10.1 Test Stand temperatures during gaseous He cool down of VMTF and TQS01.

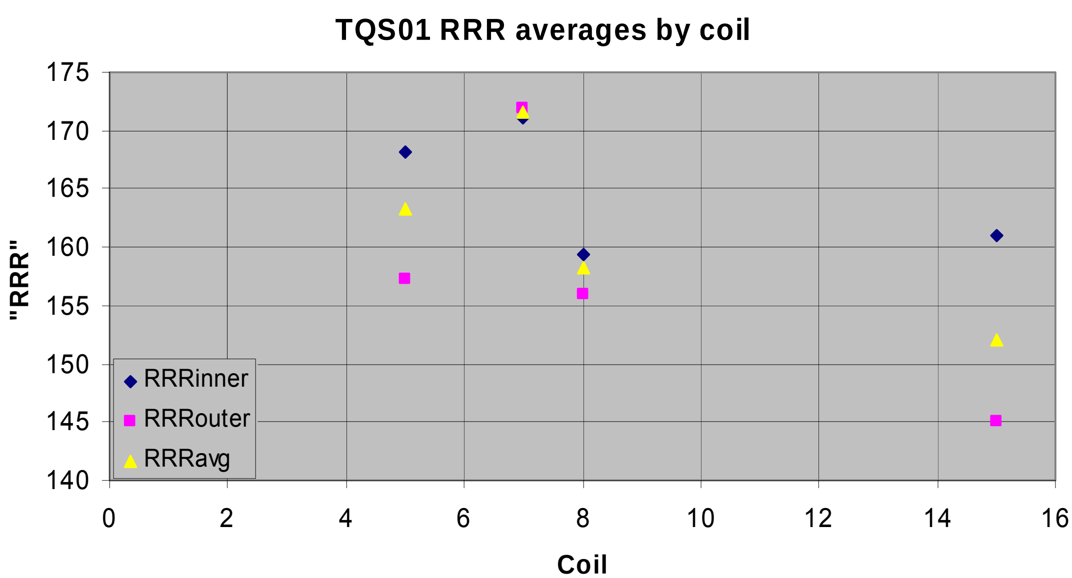


Fig. 10.2. RRR of inner layer, outer layer, and average for each coil (coils 5, 7, 8 and 15)

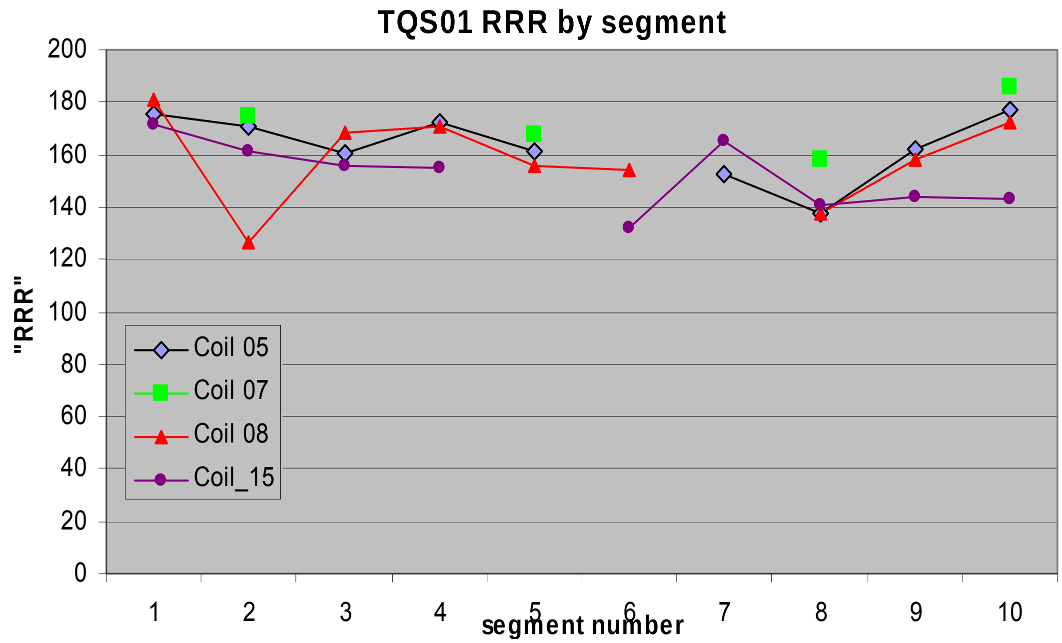


Figure 10.3. RRR of segments (numbers correspond to the segments listed in Table 10.1)

	Coil 5	Coil 7	Coil 8	Coil 15
1	05A2_A3	07A3_A2	08A3_A2	15A2_A3
2	05A3_A4	07A5_A3	08A4_A3	15A3_A4
3	05A4_A5	07A6_A5	08A5_A4	15A4_A5
4	05A5_A6	07A7_A6	08A6_A5	15A5_A6
5	05A6_A7	07A8_A7	08A7_A6	15A6_A8
6	05A7_B6	07B6_A8	08A8_A7	15A8_B6
7	05B6_B5	07B5_B6	08B5_A8	15B6_B5
8	05B5_B4	07B4_B5	08B4_B5	15B5_B4
9	05B4_B3	07B3_B4	08B3_B4	15B4_B3
10	05B3_B2	07B2_B3	08B2_B3	15B3_B2

Table 10.1 List of segments with RRR plotted in Fig 10.3 (data not available if segment is read)

11. Voltage Spikes

The voltage spike detection system (VSDS) was used to capture half coil voltage signals in a 500 ms window whenever the half coil difference exceeded a threshold of 100-130 mV (depending on the ramp). This threshold was relatively large compared with our usual setting of about 15-25 mV, due to the level of noise on half coil signals (which may be due to the way in which these were wired and shielded). These voltage data are available for each training ramp, until the system failed on ramp 26 due to a power supply problem. Analysis of the spike data is still in progress. A few examples of big spikes are shown in the following.

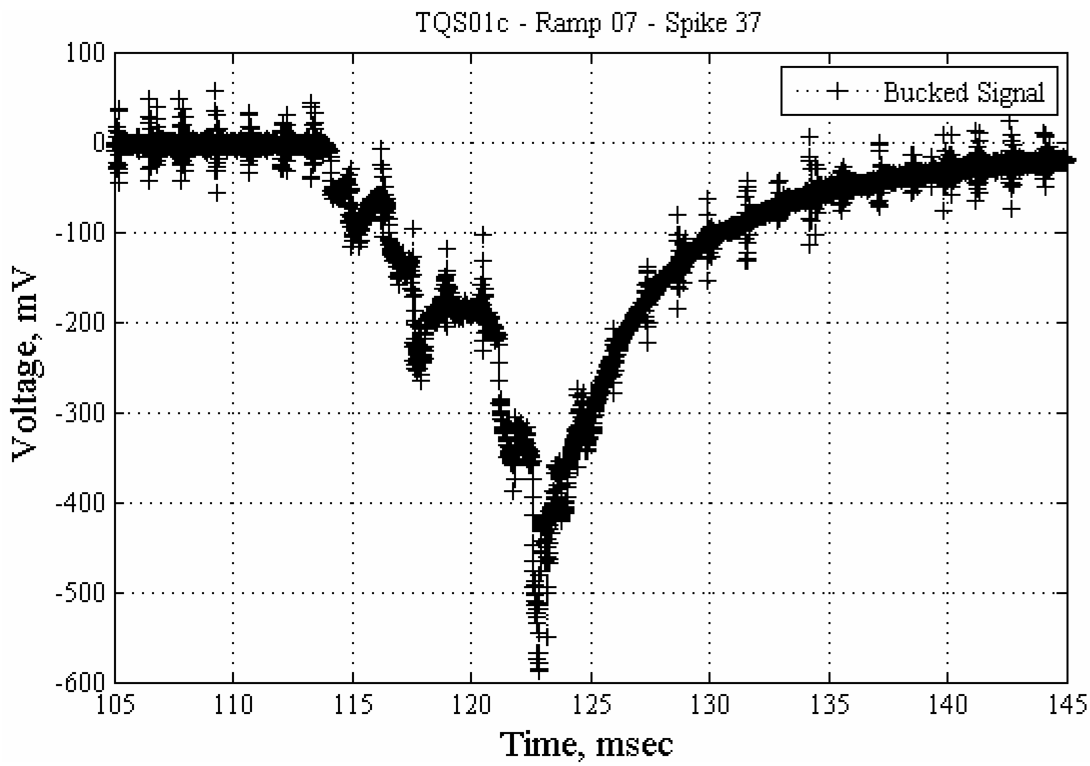


Figure 11.1. Voltage spike recorder during ramp 7. It didn't trigger the quench protection system. Quench detection threshold was 600 mV.

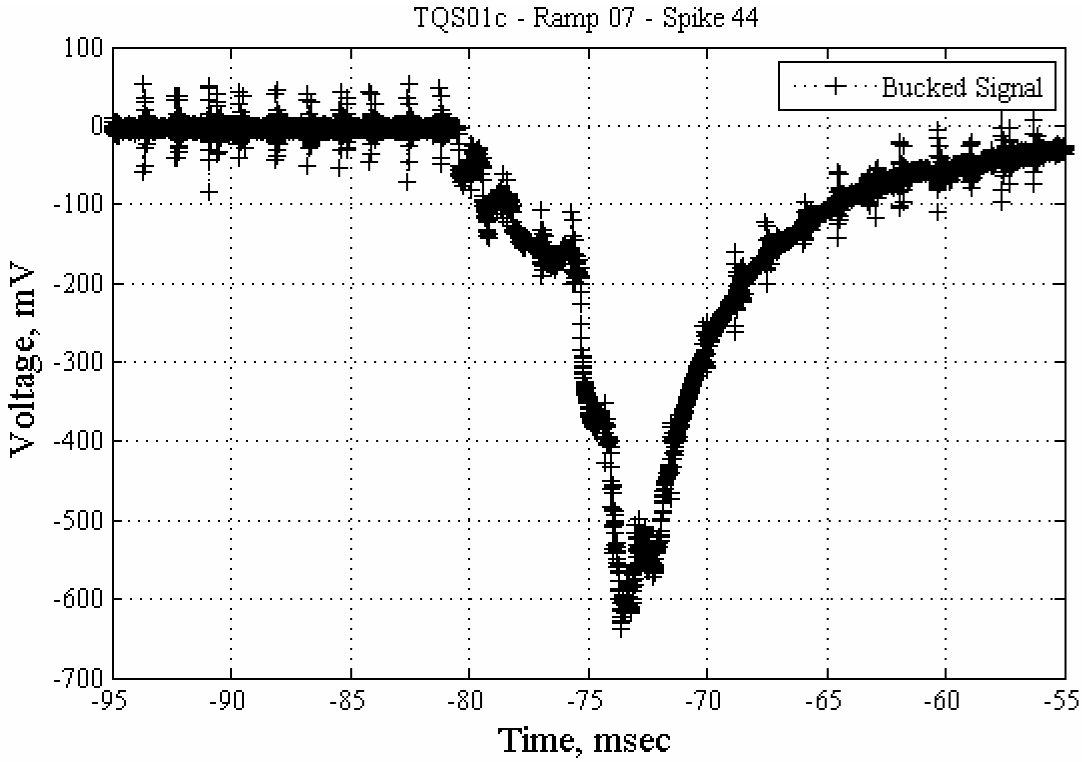


Figure 11.2. Another big voltage spike, recorder during ramp 7, that didn't trigger the quench protection system.

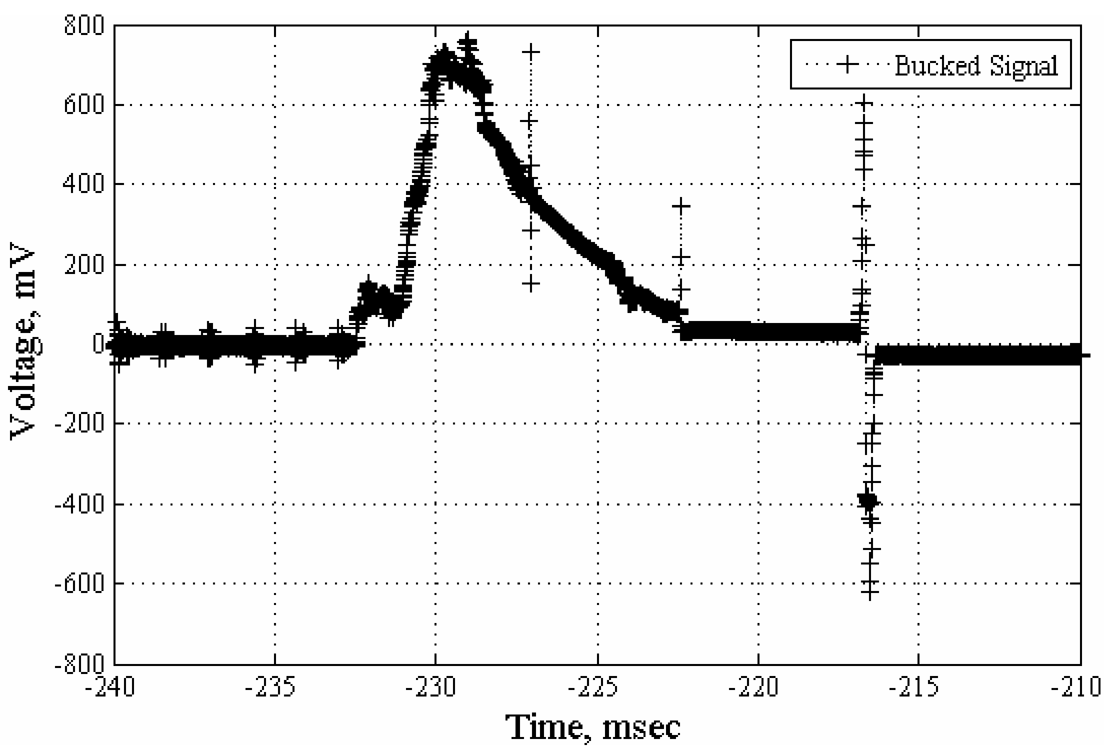


Figure 11.3. Voltage spike, recorder during ramp 10, that triggered the quench protection system. Quench detection threshold was 600 mV